ANNUAL TECHNICAL REPORT

Urban and Regional Seismic Monitoring—Wasatch Front Area, Utah, and Adjacent Intermountain Seismic Belt

Year Two: January 1 – December 31, 2002

U.S. Geological Survey Cooperative Agreement No. 01HQAG0014

Dr. Walter J. Arabasz, Principal Investigator
Dr. Robert B. Smith, Co-Principal Investigator
Susan J. Nava, Co-Investigator
Dr. James C. Pechmann, Co-Investigator
Dr. Kristine L. Pankow, Co-Investigator

University of Utah
Department of Geology and Geophysics
135 South 1460 East, Room 705 WBB
Salt Lake City, UT 84112-0111
Tel: (801) 581-6274 Fax: (801) 585-5585
E-mail: arabasz@seis.utah.edu
URL: www.seis.utah.edu

USGS Project Officer: Dr. John Unger
USGS Administrative Contracting Officer: Sherry Ly Newman

Program Element: Seismic Networks
Key Words: Regional Seismic Hazards, Real-time Earthquake Information, Seismotectonics, Engineering Seismology

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W. J. Arabasz, R. B. Smith, S. J. Nava , J. C. Pechmann, and K. L. Pankow
University of Utah
Department of Geology and Geophysics
135 South 1460 East, Room 705 WBB
Salt Lake City, UT 84112-0111
Tel: (801) 581-6274 Fax: (801) 585-5585
E-mail: arabasz@seis.utah.edu
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Non-technical Summary
January 1 – December 31, 2002

This cooperative agreement provides major support for urban and regional seismic monitoring in the study area. It also helps support the operation of a regional earthquake-recording and information center. During 2002 we successfully completed a basic real-time earthquake information system in the Wasatch Front area—as part of an Advanced National Seismic System (ANSS)—in time for 24/7 operation for public safety during the 2002 Salt Lake City Winter Olympics. An important feature of the real-time system is the capability to automatically generate computer maps of the severity of ground shaking within minutes of an earthquake. We later added 20 more stations to the Wasatch Front urban network, which included 65 ANSS-funded strong-motion stations at the end of 2002. A total of 1,058 seismic events were located by the regional seismic network in our Utah study region during 2002; eight had a magnitude of 3.0 or larger, and two were reported felt. The largest local earthquakes were shocks of magnitude 3.6—one on January 20 in southwestern Utah and another on July 28 in northern Utah. Besides modernizing our earthquake-recording network and advancing our capabilities for rapid earthquake alert, we improved our earthquake information products and involved local, state, and regional stakeholders in building an effective ANSS.

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Salt Lake City, UT 84112-0111
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E-mail: arabasz@seis.utah.edu
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Summary
January 1 – December 31, 2002

The cooperative agreement identified here, combined with funding from the State of Utah, provided major support for the modernization and operation of the University of Utah Seismograph Stations' (UUSS) regional and urban seismic network and for the operation of a regional earthquake-recording and information center on the University of Utah campus in Salt Lake City.

At the end of December 2002, UUSS operated and/or recorded approximately 190 stations (50% short-period, 35% strong-motion, 15% broadband). USGS support is focused on the seismically hazardous Wasatch Front urban corridor of north-central Utah, but also encompasses neighboring areas of the Intermountain Seismic Belt. Project efforts during 2002 focused on (a) successful 24/7 earthquake-monitoring operations for public safety during the 2002 Salt Lake City Winter Olympics, (b) continued development of a real-time urban strong-motion network in the Wasatch Front area as an element of an Advanced National Seismic System (ANSS), and (c) ongoing network operations.

We successfully completed a basic real-time earthquake information system in the Wasatch Front region in time for 24/7 operations during the 2002 Salt Lake City Winter Olympics. The new system was developed through joint efforts with the USGS, started in FY 2000; key components included 45 strong-motion stations, a new real-time earthquake notification and processing system (hardware and software) at our UUSS earthquake center, and capabilities for automated ShakeMaps. A joint UUSS–USGS press release described the Olympic earthquake safety efforts <*http://www.utah.edu/news/releases/02/jan/quakes.html*>, which received notable media attention.

Utah's urban strong-motion network and real-time earthquake information system were only secondarily built for the 2002 Winter Olympics. The primary motivation was to improve earthquake information in Utah's rapidly-growing Wasatch Front urban corridor for emergency response and long-term risk reduction. Accomplishments during the report period relating to real-time urban strong-motion monitoring included: (1) extensive upgrading of Earthworm computer systems (hardware and software), (2) full implementation of automated ShakeMaps and development of a new predictive attenuation relationship for peak horizontal ground velocity in extensional tectonic regimes, (3) installation of 20 additional strong-motion stations during the second half of 2002, (4) integration of USGS/NSMP strong-motion data into our earthquake information system, and (5) planning and organizational activities relating to further implementation of ANSS in Utah and in the Intermountain West region.

Besides major efforts in building our new urban strong-motion network, notable accomplishments (and related efforts) during 2002 in ongoing network operations included: (1) recalibration of the coda-magnitude scale used in the Utah earthquake catalog, 1981 to present; (2) a study of triggered seismicity in Utah from the November 2002 Denali Park earthquake; (3) advancing real-time integration with—and providing technical help to—other networks in our region; (3) efficient submission of waveform data from our network to the IRIS Data Management Center (DMC) as well as submission of catalog and event data to the ANSS earthquake catalog and Quake Data Distribution System; and (4) companion monitoring and study of mining-induced seismicity for hazard mitigation.

During the report period, we detected and analyzed approximately 6,600 seismic events, including local earthquakes, teleseismic and regional earthquakes, and blasts. A total of 3,089 earthquakes were located in the Intermountain Seismic Belt—including 1,058 within the Utah region, of which 757 were within the Wasatch Front region. Eight earthquakes of magnitude 3.0 and larger occurred in the Utah region during the report period. The two largest earthquakes each had a magnitude (M_L) of 3.6—one occurred at 17:20 UTC on January, 20, 2002, 12 km south of Beaver in southwestern Utah, and the other occurred at 19:38 UTC on July 28, 2002, 19 km WNW of Randolph in northern Utah.

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INTRODUCTION

This technical report summarizes results and accomplishments under this cooperative agreement during the period January 1–December 31, 2002.

General Background

This cooperative agreement, combined with funding from the State of Utah, provides major support for network operations associated with the University of Utah's urban/regional seismic network (190 stations at the end of 2002). Ongoing USGS support focuses on the seismically hazardous Wasatch Front urban corridor of north-central Utah and also encompasses neighboring areas of the Intermountain Seismic Belt (ISB). Under the local implementation of an Advanced National Seismic System (ANSS), we continued development of a real-time urban strong-motion network in the Wasatch Front area. The real-time responsiveness and the strong-motion aspects of the network upgrading represented a major advance towards meeting local user needs for emergency response, earthquake engineering, and science. (The siting of the 2002 Winter Olympics in and near Salt Lake City provided a secondary motivation for developing capabilities for real-time seismic monitoring in a timely way.)

Primary deliverables for this USGS support are the continuous seismic monitoring of the study area and the services of a regional earthquake recording and information center. Information products and services include rapid earthquake alert, a modern Web site with near-real-time earthquake information, earthquake catalogs (issued on a quarterly basis in preliminary form and periodically in finalized form), automated transfer of hypocentral, waveform, and arrival-time data to other outlets prescribed by the USGS for broad access, and extensive expert assistance to individuals and groups in earthquake education and awareness, public policymaking, planning and design, and hazard and risk assessment.

Scientific objectives include the characterization of tectonic framework and earthquake potential, surveillance of space-time seismicity and characteristics of small-to-moderate earthquakes (for understanding the nucleation of large earthquakes in the region), and the documentation and evaluation of various earthquake-related parameters for accurate hazard and risk analyses. Scientific results are routinely reported to the USGS under separate research awards.

Hazard, Risk, and Benefits to NEHRP of this State-Federal Partnership

Earthquakes pose the greatest natural threat for destruction of life and property in Utah. On a national level, the relative hazard and risk in Utah's densely populated Wasatch Front area led the USGS to target this area for an urban strong-motion network of 500 instruments in its 1999 report to Congress for an Advanced National Seismic System (ANSS) (USGS Circular 1188). The Federal Emergency Management Agency (FEMA) ranks Utah seventh in the Nation in absolute risk and sixth in relative risk when one takes the ratio of the average annualized earthquake loss to the replacement value of the building inventory (FEMA, 2000).

More than three-quarters of Utah's population and economy are concentrated in the Wasatch Front area, literally astride the five most active segments of the Wasatch fault. Population in the Ogden-Salt Lake City-Provo urban corridor is growing dramatically from its 1995 base of 1.6 million and is projected to reach 2.7 million by 2020 and 5 million by 2050.

The Wasatch Front area occupies an active segment of the ISB—roughly centered on the 343-km-long Wasatch fault zone. Diffuse shallow seismicity, Holocene normal faulting, and episodic surface-faulting earthquakes of M6.5 to M7.5+ characterize the area. The Wasatch fault is notable as the longest continuous, active normal fault in the United States (10 discrete segments)—with five central segments between Brigham City and Nephi (see Figure 3) having an average length of about 50 km, Holocene slip rates of 1-2 mm/yr, and average recurrence intervals ranging from about 1,300 to 2,800 yr (Machette et al., 1991; McCalpin and Nishenko, 1996). One of the most active segments is the Salt Lake City segment, which has produced large, M~7, surface-faulting earthquakes on the average of once every 1,350 ± 200 years during the past 6,000 years, with the last one occurring 1,230 ± 60 years ago (Black et al., 1995; McCalpin and Nishenko, 1996; McCalpin and Nelson, 2000).

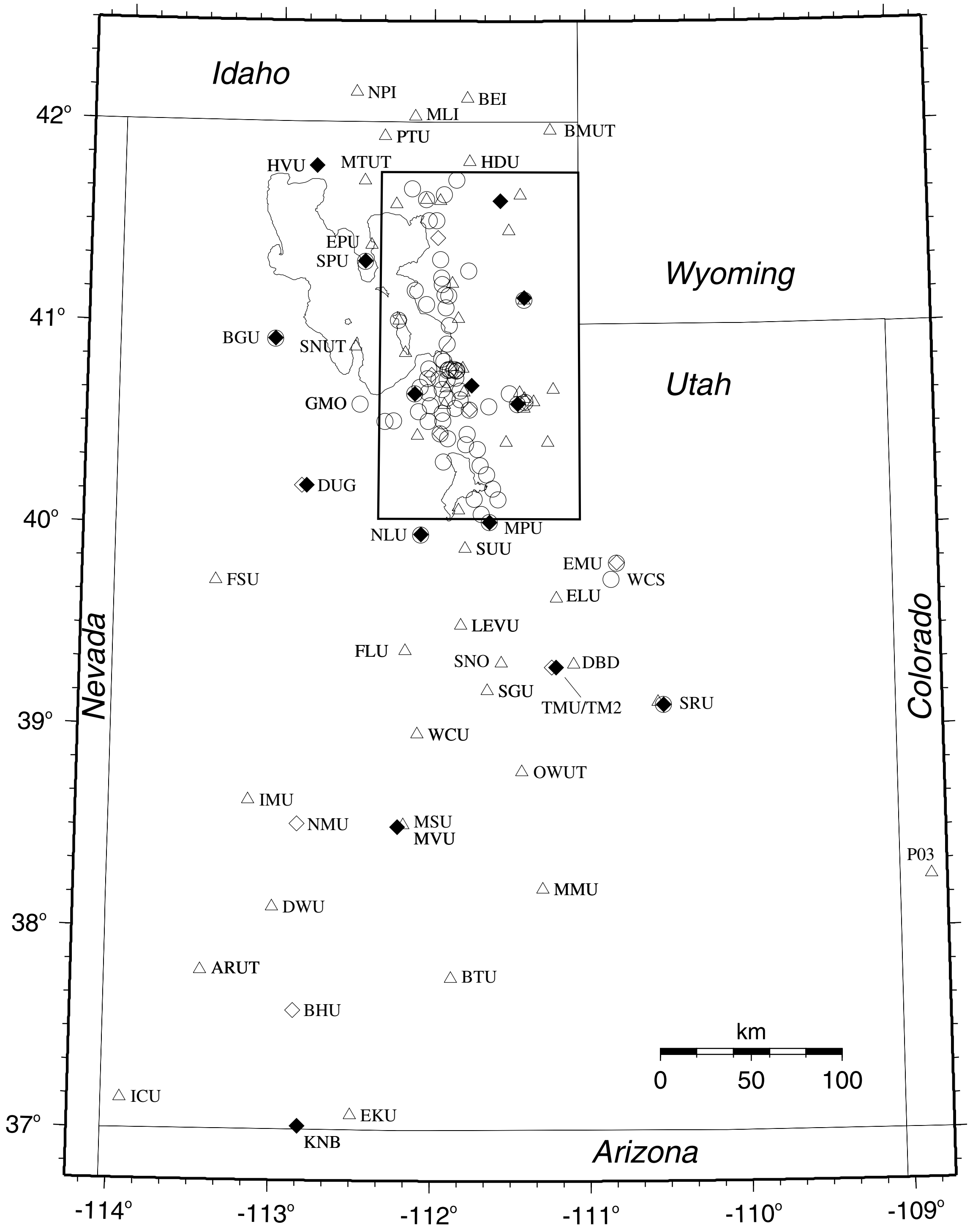
The National Seismic Hazard Maps of Frankel et al. (1996, gridded data) indicate relatively high ground-shaking hazard for the Wasatch Front—reflected, for example, by the following values of peak ground acceleration in the Salt Lake Valley for specified probabilities of exceedance: 0.30 g (10% in 50 yr), 0.53 g (5% in 50 yr), 0.87 g (2% in 50 yr). Expected direct economic losses to buildings and lifelines for a scenario M7.5 earthquake centered in Salt Lake County are approximately $12 (±3) billion (Rojahn et al., 1997). The addition of indirect economic and social losses would lead to higher total loss.

Both NEHRP and the USGS derive great benefit from this project in the form of (1) significant cost-sharing by the state of Utah under this state-federal partnership and (2) wide-ranging activities by University of Utah seismologists which effectively relieve the USGS from having to meet the same first-order needs in this region. Importantly, the combined state-federal funding allows balance between the practical necessities of a *regional* seismological approach and careful attention to Utah's urban corridor.

Regional Seismic Network

Figures 1 and 2 together with Table A-1 (Appendix A) summarize essential information for the University of Utah's urban/regional seismic network, which included 190 stations at the end of 2002. The locations of conventional broadband and short-period stations forming the regional network are shown in Figure 1. Figure 2 shows the location of strong-motion stations installed by the end of 2002 as part of the new urban network.

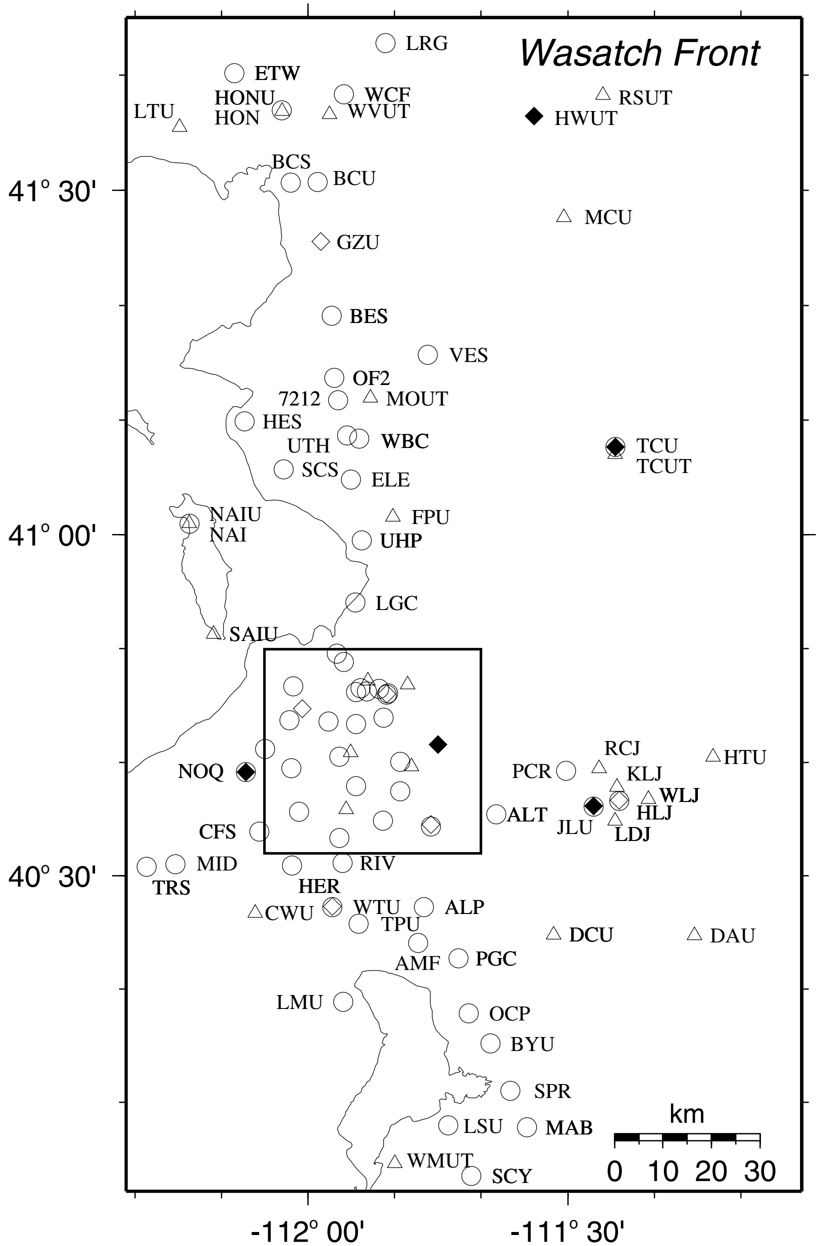
Utah Regional/Urban Seismic Network
December 2002

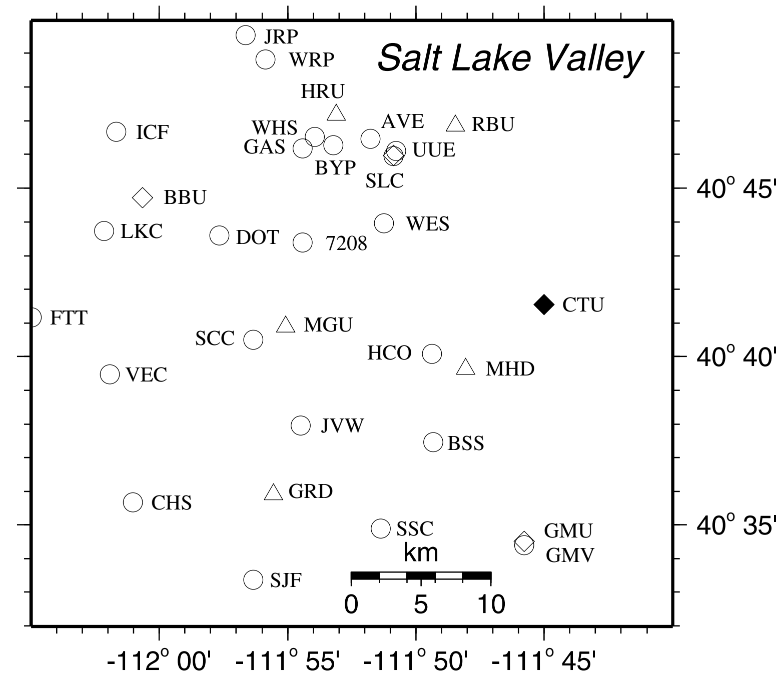


triangles = vertical-component stations;
diamonds = multi-component stations;
solid diamonds = broadband, digitally-telemetered stations;
circles = strong motion, digitally-telemetered stations.

Figure 1

Utah Urban Seismic Network
December 2002





triangles = vertical-component stations;
diamonds = multi-component stations;
solid diamonds = broadband, digitally-telemetered stations;
circles = strong motion, digitally-telemetered stations.

Figure 2

The urban/regional network consists of 112 stations focused on the Wasatch Front area, an additional 22 stations that provide expanded coverage of the Utah region (chiefly central and southwestern Utah), and another 56 stations covering the continuation of the Intermountain Seismic Belt from south-central Idaho to Yellowstone National Park (separate USGS support is provided for the Yellowstone network). As indicated in Table A-1 (Appendix A), during the period of this award 39 of the 190 stations were maintained by other institutions—six by the Idaho National Engineering and Environmental Laboratory and 14 by either the USGS, Sandia National Lab, or Lawrence Livermore National Lab as part of the USNSN. The University of Utah handled the field repair and maintenance of 152 stations, 105 of which were sponsored by the USGS under this award.

RESULTS AND ACCOMPLISHMENTS

Overview of Seismicity

During the report period, we detected and analyzed approximately 6,600 seismic events. Of these 47 percent were local earthquakes in the Utah region, 35 percent were regional earthquakes and teleseisms, and 18 percent were blasts. A total of 3,089 earthquakes were located in the Intermountain Seismic Belt, including 1,058 within the Utah region (Figure 3) and 757 within our standard Wasatch Front region (38° 55'–42° 30' N, 110° 25'–113° 10' W). Eight earthquakes of magnitude 3 or larger occurred in the Utah region (Figure 4, Table 2). The two largest earthquakes each had a magnitude (M_L) of 3.6—one occurred at 17:20 UTC on January, 20, 2002, 12 km south of Beaver in southwestern Utah, and the other occurred at 19:38 UTC on July 28, 2002, 19 km WNW of Randolph in northern Utah.

Two earthquakes in the Utah region during the report period were documented as felt, coincidentally the two magnitude 3.6 shocks noted above (Table 2). The University of Utah Seismograph Stations issued two press releases during the report period immediately after earthquakes in the Utah region that were either felt by many or larger than a set threshold magnitude of 3.5. About 29 percent of the seismicity detected in the Utah region during the report period was associated with areas of ongoing coal-mining-related seismicity in east-central Utah and included 311 shocks ($M_L \leq 2.6$) located within an arcuate zone extending counterclockwise from immediately northeast of Price to 100 km southwest of it (Figure 3).

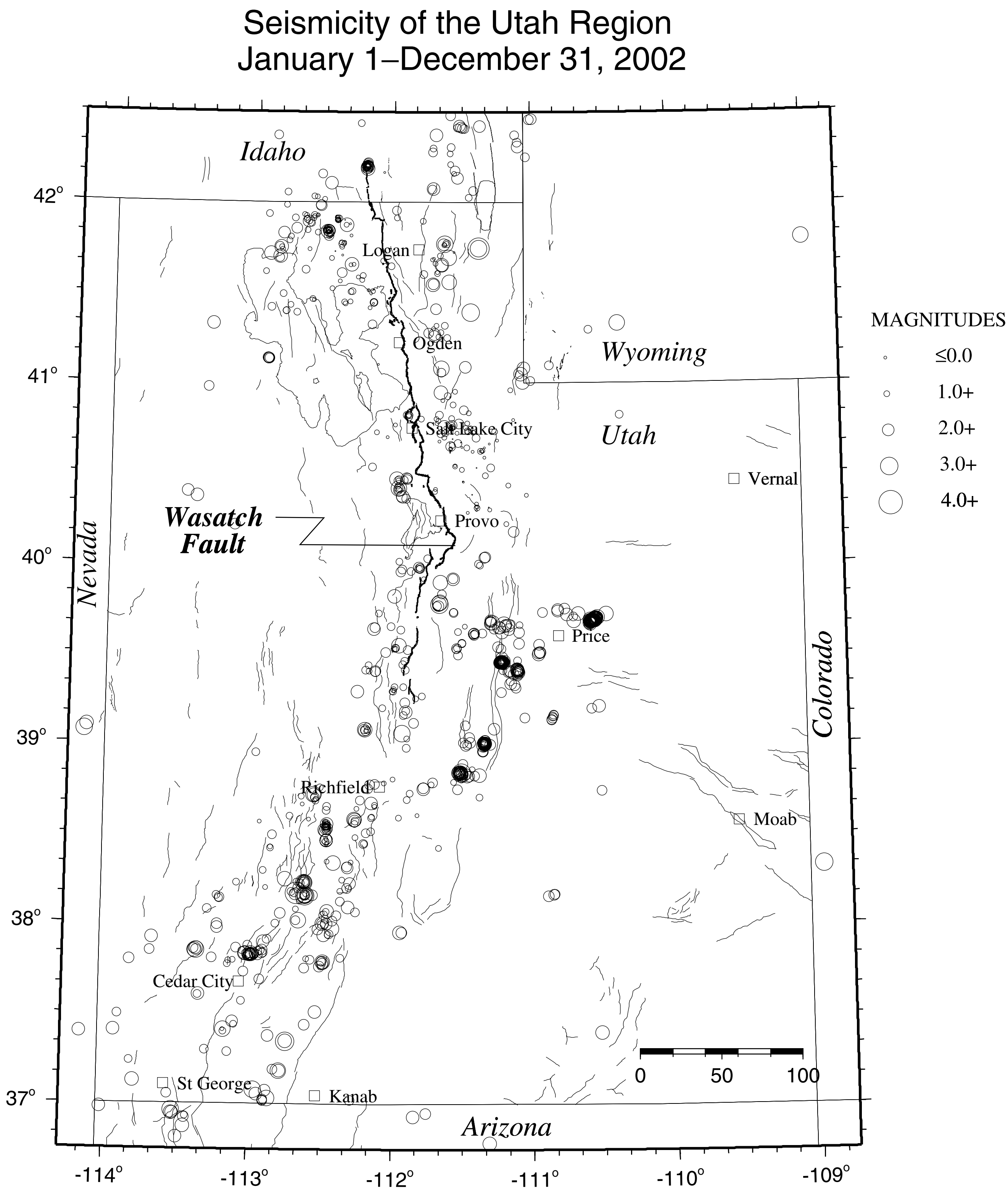


Figure 3. Earthquake epicenters (N=1,058) located by the University of Utah Seismograph Stations, superposed on a map of Quarternary (geologically young) faults compiled by the Utah Geological Survey. The Wasatch fault is shown in bold.

Earthquakes of Magnitude 3.0 and Larger
January 1–December 31, 2002

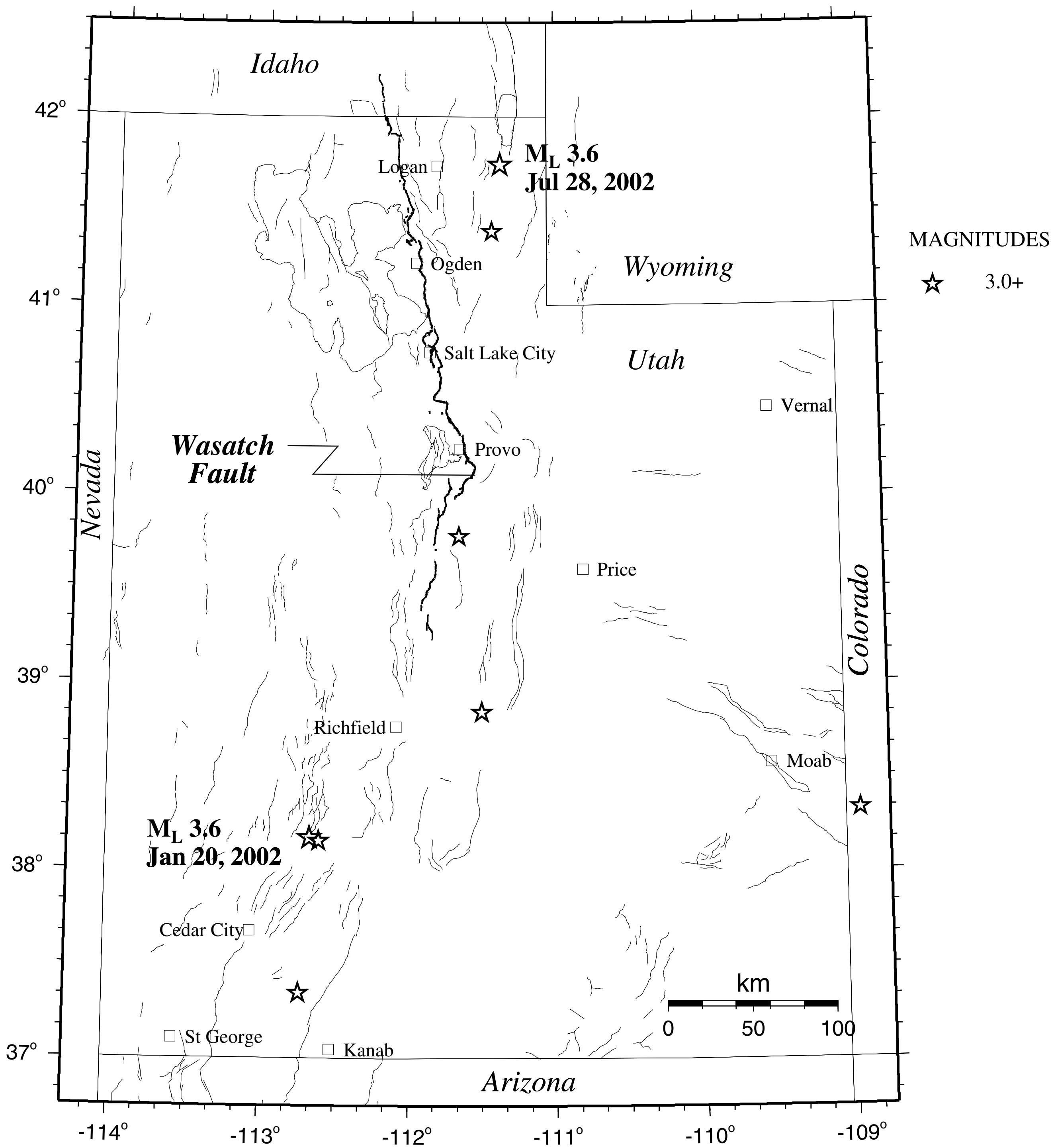


Figure 4. Epicenter map of shocks of magnitude 3.0 and larger in the Utah Region during the period January 1–December 31, 2002 (base map as in Figure 4).

Table 1

Earthquakes in the Utah Region of Magnitude 3.0 and Larger, 2002

date	*origin time*	*latitude*	*Longitude*	*depth*	*mag*	*no*	*gap*	*dmn*	*rms*
020108	1726 6.54	37° 20.91′	112° 43.93′	6.7*	3.1W	12	87	29	0.23
020120	1720 13.06	38° 10.32′	112° 40.04′	0.5*	3.6W	16	64	30	0.38
020606	1229 10.67	38° 19.35′	108° 57.04′	1.2*	3.0W	11	167	12	0.53
020614	0745 46.38	41° 23.48′	111° 26.14′	7.1	3.0W	26	157	10	0.17
020728	1938 40.03	41° 44.71′	111° 22.71′	9.5	3.6W	30	147	13	0.22
020812	0131 40.64	38° 9.28′	112° 36.30′	0.2*	3.2W	19	57	35	0.17
021108	1255 22.33	38° 50.44′	111° 30.23′	5.8	3.2W	17	64	10	0.19
021109	0809 51.69	39° 46.42′	111° 39.85′	3.3*	3.0W	24	71	17	0.17

number of earthquakes = 8

* indicates poor depth control
W indicates Wood-Anderson data used for magnitude calculation

Table 2

Felt Earthquakes In The Utah Region
January 1 to December 31, 2002

Date	Time†	Felt Information*	Latitude	Longitude	Magnitude §
Jan 20	17:20 10:20 a.m. MST	Beaver, Utah	38º 10.32'	112º 40.04'	M_L 3.6
July 28	19:39 1:38 p.m. MDT	Laketown, Utah	41º 44.71'	111º 22.71'	M_L 3.6

† Times are listed first as UTC, then as Local Time.

* Felt information as reported to the University of Utah Seismograph Stations unless otherwise noted.

§ Local magnitude (M_L) from University of Utah (UUSS).

Olympic Earthquake Safety

We successfully completed a basic real-time earthquake information system in the Wasatch Front region in time for 24/7 operations during the 2002 Salt Lake City Winter Olympics. The new system was developed through joint efforts with the USGS, started in FY 2000; key components included 45 strong-motion stations, a new real-time earthquake notification and processing system (hardware and software) at our UUSS earthquake center, and capabilities for automated ShakeMaps. A joint UUSS–USGS press release described the Olympic earthquake safety efforts <*http://www.utah.edu/news/releases/02/jan/quakes.html*>, which received notable media attention.

The Olympics safety project involved, among other things, (1) coordination for more than three years with the Utah Olympic Public Safety Command; (2) arrangements for high-performance, fault-tolerant Web service by Akamai during the Olympic time period; (3) "hardening" of our UUSS earthquake recording center; (4) contingency planning with NEIC, the USGS Earthworm group in Golden, CO, USGS seismologists in Menlo Park, CA, and the TriNet ShakeMap group—all aimed at backup for emergency response, data processing, and posting of Web information; (5) establishing emergency radio and satellite-phone links between UUSS and the Utah Division of Comprehensive Emergency Management; (6) creation of an extensive, written in-house user guide for emergency earthquake response; and (7) continuous 24/7 onsite staffing of our earthquake center during the Olympic time period.

Real-Time Urban Strong-Motion Monitoring

Utah's urban strong-motion network and real-time earthquake information system, mentioned above, were only secondarily built for the 2002 Winter Olympics. The primary motivation was to improve earthquake information in Utah's rapidly-growing Wasatch Front urban corridor for emergency response and long-term risk reduction. In the following subsections, we describe some specific related accomplishments.

Earthworm — In advance of the February 2002 Olympics, great time and effort went into readying Earthworm computer systems (hardware and software) for real-time earthquake monitoring and automated alerts. The data acquisition/processing systems were extensively upgraded and expanded in 2001 and early 2002 with joint USGS-University of Utah funding. Considerable efforts were made—both before and after the Olympics—to test the software, fine tune it to minimize false alarms, and report problems to the USGS Earthworm team.

ShakeMap and attenuation studies — ShakeMap software was fully implemented and automated prior to the 2002 Salt Lake City Winter Olympics with the collaborative involvement of the USGS, the Utah Geological Survey, and the Utah Division of Comprehensive Emergency Management (see <http://www.seis. utah.edu/shake>). In order to automate ShakeMap in Utah, software interfacing the

Earthworm real-time monitoring system with ShakeMap had to be written. This was a two-fold project: (1) the USGS provided an Earthworm module that automatically processes the data and writes ShakeMap compatible files; (2) we then wrote accessory ShakeMap modules that watch for the Earthworm output files, prioritize earthquakes for processing, and start ShakeMap. During the year 2002, ShakeMaps were automatically generated for four earthquakes, ranging in magnitude from 3.0 to 3.7.

ShakeMap is by no means a static program. In the summer of 2002, version 2.4 was released. Among other things, the new version provided additional attenuation relations, added topography to the intensity map, and switched file formats from GIF to JPEG. We installed a pre-release version and helped with the testing. In this version, a Utah-written module for sending ShakeMaps as email attachments was included as a supplementary module. It will be fully incorporated in the next version. We have also customized the *cancel* module to properly restore the Utah Archive section of the ShakeMap webpage following false alarms.

To ensure our operational ability to produce ShakeMaps and maintain quality control, this past year we compiled an in-house ShakeMap Guide. This guide includes: an overview of the program, how to switch to the back-up machine, how to initially test the veracity of the maps, how to remove false alarms, how to manually process the data, and example ShakeMaps.

Because ShakeMap requires predictive relations for attenuation and site amplification, part of our ShakeMap development has involved testing the appropriateness of the chosen predictive relations and site amplification. We have used ground-motion data acquired by our new strong-motion network, together with site amplification factors developed for the Wasatch Front region, to validate the appropriateness of using weak-motion attenuation relations developed in southern California. Further, we have used a worldwide strong-motion data set assembled by Spudich et al. (1999) in order to determine a predictive relation for peak horizontal ground velocity (PGV) for earthquakes in extensional tectonic regimes (Pankow et al., 2002a).

The new PGV regression has been incorporated into our routine ShakeMap processing. It has also been given to the University of Nevada at Reno for ShakeMap implementation in Nevada. The details of the PGV regression and a correction we made to account for the 20% bias at rock sites reported by Spudich et al., (1999) have been described by Pankow and Pechmann and submitted as a Short Note to the *Bulletin of the Seismological Society of America* (a preprint is included here as Appendix B).

20 new strong-motion stations — During the second half of FY 2002, we added 20 more ANSS strong-motion stations, at 17 urban-reference sites and three free-field rock sites, to Utah's urban strong-motion network. The ANSS network now has 65 UUSS/ANSS stations (see Figures 1 and 2). Major efforts during the first quarter of FY 2002, prior to the Olympics, went into completing real-time telemetry (using frame-relay telephone, spread-spectrum radio, or public-Internet links), instrument calibration, and continuous centralized recording of 25 strong-motion stations installed in late FY 2001.

Integration of USGS/NSMP strong-motion data — The USGS National Strong-Motion Program (NSMP) currently operates several digital strong-motion stations in the Wasatch Front area from which data are retrieved by telephone remotely from Menlo Park, CA. In April 2002 we began recording continuous data streams from two of these stations via telemetry links we installed. In mid-September 2002 we began using an import protocol to automatically receive from NSMP both parametric data (in XML format) and waveform data for all their strong-motion stations in the Wasatch Front area operating with telephone connections. The NSMP data usefully contribute to our ShakeMap database.

ANSS planning activities — During FY 2002, a 12-member state-level advisory committee continued to guide the development and effective use of urban strong-motion monitoring in Utah. The committee was created in FY 2001, both as part of the ANSS management structure and as part of Utah's state earthquake program. In late FY 2002, an ANSS implementation plan for FY 2003 was developed both for the state of Utah and for the Intermountain West (IMW) Region (see Arabasz, 2002a, b).

Accomplishments in Ongoing Network Operations

Important accomplishments during the report period included: (1) recalibration of the coda-magnitude scale used in the Utah earthquake catalog, 1981 to present; (2) a study of triggered seismicity in Utah from the November 2002 Denali Park earthquake; (3) advancing real-time integration with—and providing technical help to—other networks in our region; (3) efficient submission of waveform data from our network to the IRIS Data Management Center (DMC) as well as submission of catalog and event data to the ANSS earthquake catalog and Quake Data Distribution System; and (4) companion monitoring and study of mining-induced seismicity for hazard mitigation. The following descriptions provide more detail for these and other efforts.

Correction of systematic time-dependent coda-magnitude errors in the Utah and Yellowstone National Park Region earthquake catalogs, 1981–2002 — We have calibrated new coda-magnitude (M_C) equations for local earthquakes digitally recorded since 1981 in the Utah (UT) region and since 1984 in the Yellowstone National Park (YP) region—the two regions where the University of Utah Seismograph Stations (UUSS) operates regional seismic networks. The primary motivation for this study was the recognition of systematic time-dependent $M_C - M_L$ differences ranging up to 0.4 and 0.9 units in the UT and YP regions, respectively. The new M_C equations are:

$$M_C = -2.25 + 2.32 \log \tau + 0.0023\Delta \quad \text{in the UT region,}$$

$$M_C = -2.60 + 2.44 \log \tau + 0.0040\Delta \quad \text{in the YP region,}$$

where Δ is epicentral distance in km and τ is signal duration in sec on a short-period vertical-component record, measured from the P-wave onset to the time that the signal drops below the noise level. The M_C equations were calibrated against local magnitudes (M_L) determined from paper and synthetic Wood-Anderson records, using data from 926 UT and 510 YP earthquakes of M_L 0.5 to 4.7. Improved signal duration measurements were made by (1) using a fixed noise level instead of the preevent noise level, (2) applying instrument gain corrections using an experimentally-verified method, and (3) fixing a relatively minor coding error in UUSS software for automatically finding signal durations. To determine the constants in the M_C equations, we used an orthogonal regression method rather than linear regression. The latter produces biased results because the errors in the predictor variables (log τ and Δ) are not negligible compared to the errors in the response variable (M_L).

Consistency between M_C and M_L estimates in the UUSS catalogs is essential because M_Ls, while preferred, are consistently available only for earthquakes of $M_L > 4$ and are unavailable for most earthquakes of $M < 3$. The new M_C equations, in combination with the corrections to the duration measurements, reduce average M_C-M_L differences to 0.1 magnitude units or less for $M_L < 5$ events. The range of verified applicability of the new Mc equations is currently restricted to $M_L < 5$ because the finite record lengths of UUSS recording system triggers appear to have caused underestimation of signal durations for larger earthquakes. The new M_C equations, and M_L station corrections from a companion study, will be used to revise M_C and M_L magnitudes in the UT and YP region earthquake catalogs for 1981–present and 1984–present, respectively. The revisions should significantly improve the homogeneity of these magnitudes, allowing more accurate recurrence rate estimates and other statistical analyses.

Triggered seismicity in Utah from the November 3, 2002, Denali Fault earthquake — Coincident with the arrival of the surface waves from the November 3, 2002, Mw 7.9 Denali Fault, Alaska earthquake (DFE), the University of Utah Seismograph Stations (UUSS) regional seismic network detected a marked increase in seismicity along the Intermountain Seismic Belt (ISB) in central and north-central Utah (Pankow et al., 2002b, 2003). The number of earthquakes increased from 0.26/day during the 1038 days before the DFE to 0.67/day during the 12 days after. The increased seismicity was characterized by small magnitude events ($M = 3.2$) and concentrated in five distinct spatial clusters within the ISB between 38.75°and 42.0° N (Figure 5). The first of these earthquakes was an M 2.2 event located ~20 km east of Salt Lake City, Utah, which occurred during the arrival of the Love waves from the DFE.

The increase in Utah earthquake activity at the time of the arrival of the surface waves from the DFE suggests that these surface waves triggered earthquakes in Utah at distances of more than 3,000 km from the source. We estimated the peak dynamic shear stress caused by these surface waves from measurements of their peak vector velocities at 43 recording sites: 37 strong-motion stations of the Advanced National Seismic System and six broadband stations. (The records from six other broadband instruments in the region of interest were clipped.) The estimated peak stresses ranged from 1.2 bars to 3.5 bars with a mean of 2.3 bars, and generally occurred during the arrival of Love waves of ~15 sec period. These peak dynamic shear stress estimates are comparable to those obtained from recordings of the 1992 M_W 7.3 Landers, California, earthquake in regions where the Landers earthquake triggered increased seismicity.

Based on statistical analysis we can reject with > 95% confidence the null hypothesis that the increased seismicity in Utah can be explained by stationary random occurrence. Distantly triggered seismicity is most commonly associated with areas characterized by recent volcanic or geothermal activity.

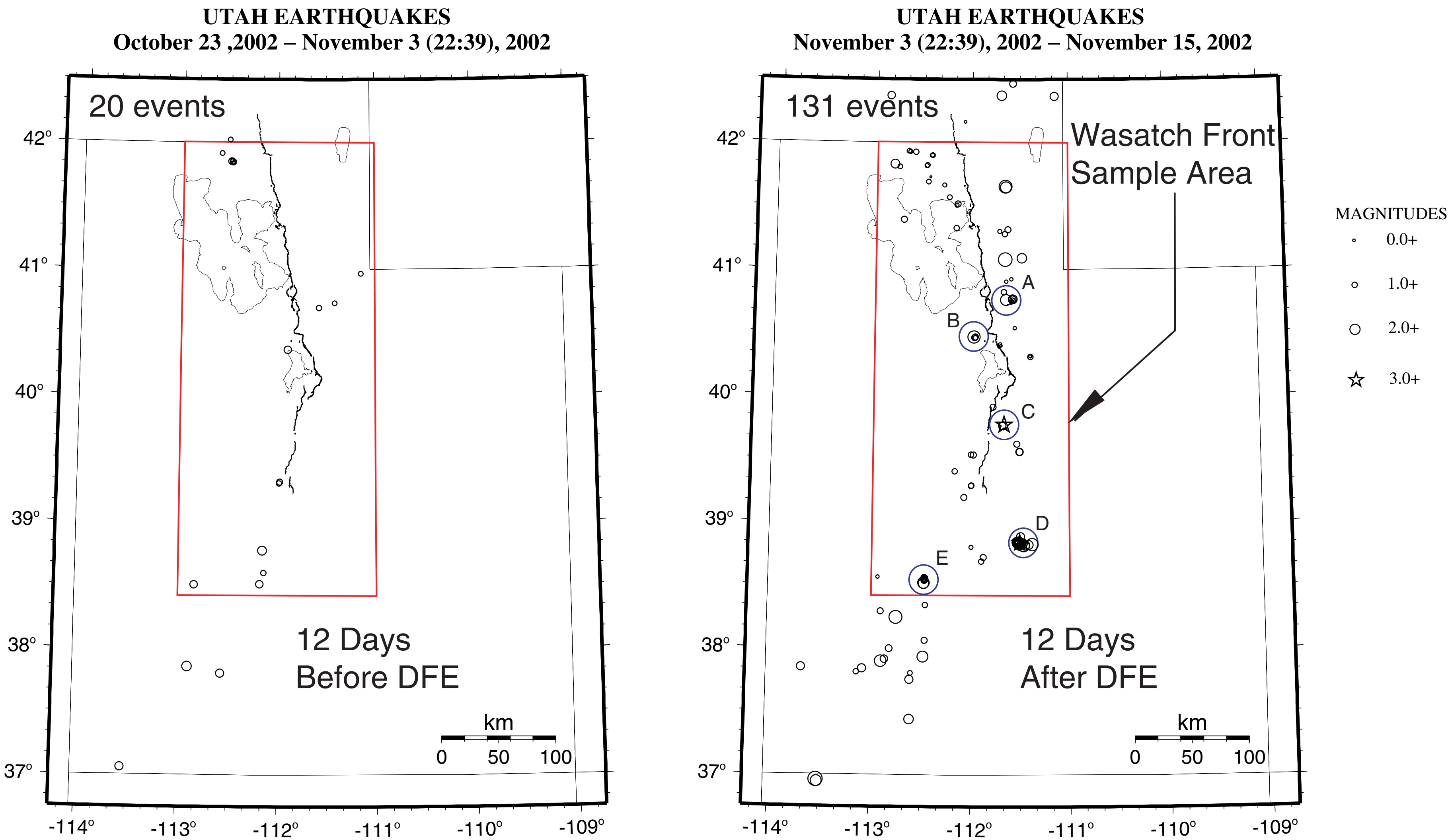


Figure 5. Comparison of seismicity in Utah immediately before and after the DFE. Data from the University of Utah regional seismic network. The circles labeled A-E mark clusters of local earthquakes which occurred following the DFE.

However, as instrumentation and station coverage improves detecting triggered seismicity in more typical crustal environments also improves.

hypoDD — To perform more detailed analyses of seismicity patterns in selected areas, we obtained and began experimenting with the double-difference earthquake location algorithm hypoDD (Waldhauser and Ellsworth, 2000; Waldhauser, 2001). This program uses travel times recorded at the same station from different earthquakes to obtain optimal relative earthquake locations. During the report period, routines were written that allowed us to import our phase picks into hypoDD, and we also performed an extensive exploration of the input parameters and weighting schemes. The testing was done using a set of earthquakes that occurred between 1981 and 2002 within 100 km of a point of interest in the Wasatch Front area. The results of the testing were presented in an in-lab seminar. The code is locally on-line for our research use and is currently being used to study local clusters of earthquakes triggered in Utah by the Denali Fault Earthquake.

Near-real-time integration with other regional networks — We continued to expand and enhance the exchange of waveform data in near-real-time with the National Earthquake Information Center, the Idaho National Environmental and Engineering Laboratory, the U.S. Bureau of Reclamation, the Montana Bureau of Mines and Geology, and the University of Nevada, Reno. Data exchange is done via the Internet using Earthworm import/export software modules.

Assistance to other networks in the Intermountain West Region —We provided voluntary technical help to two other networks in our region. We installed software for Mike Stickney, the operator of Montana's regional seismograph network, to help him (1) create dataless SEED volumes (including instrument response information) for submission of their seismic data to the IRIS DMC and (2) enable the ANSS "Recent Earthquakes" Web interface for rapidly posting information on Montana earthquakes on the Web. We also provided customized software for calculating Richter local magnitude (M_L) from broadband waveforms. We helped Mark Lovell, a small network operator at Brigham Young University-Idaho by giving him a day-long training class in Earthworm installation and maintenance procedures and by installing the latest version of Earthworm on a PC for him to install in his earthquake recording lab.

Archiving waveform data — All digital waveform data collected by the University of Utah regional seismic network during the report period were submitted to the IRIS DMC. In June 2002, we stopped sending daily ftp waveform submissions to the DMC; instead, IRIS began directly pulling waveform data from a UUSS public waveserver into the IRIS BUD system via an Earthworm client connection. Also, at the request of the IRIS DMC, the University of Utah began acting as a pass-through agent to send continuous waveform data to the DMC from the INEEL regional seismic network in eastern Idaho and U.S. Bureau of Reclamation's "Jackson Lake" regional seismic network in eastern Idaho–western Wyoming.

ANSS earthquake catalog — During the report period, analyst-reviewed earthquake locations for the Utah (and Yellowstone) regions were automatically submitted to the ANSS catalog four times per day during the Monday-Friday work week. In January 2002, we began submitting Earthworm automatic (non-human-reviewed) hypocentral data into the Quake Data Distribution System (QDDS) for earthquakes of magnitude 3.0 and larger in our authoritative regions (Utah and Yellowstone National Park). Later, in June 2002, we began automatically submitting hypocentral data to QDDS for all analyst- reviewed earthquakes in our authoritative regions. Events submitted into QDDS are automatically posted on the ANSS RecentEqs Web pages.

Coal-mining-induced seismicity — We continued studies of mining seismicity ($M_L \leq 4.2$) induced by underground coal mining in east-central Utah (Arabasz et al., 2002c, d, e) in order to serve the needs of (1) mining engineers and mine operators concerned with mine safety and (2) decision-makers dealing with the potential hazards of mining seismicity to off-site structures and facilities. The studies involved cooperative research with the USGS and the U.S. Bureau of Reclamation, including accelerographic recording and ground-motion modeling of the mining seismicity in order to evaluate the hazard of surface ground shaking.

AVAILABILITY OF DATA

All seismic waveform data archived by the University of Utah Seismograph Stations are available upon request directly from our office (typically delivered to the user in SAC ASCII or binary format). Alternatively, waveform data can be retrieved from the IRIS DMC using their SeismiQuery Web tool at *<http://www.iris.washington.edu/SeismiQuery>* (delivered in a variety of formats). Earthquake catalog data for the Utah region are available (1) via anonymous ftp *<ftp.seis.utah.edu/pub/UUSS_catalogs>*, (2) by e-mail request to *webmaster@seis.utah.edu*, or (3) via the Advanced National Seismic System's composite earthquake catalog, *<http://quake.geo.berkeley.edu/cnss/cnss-catalog.html>*. See also the University of Utah Seismograph Stations homepage at *<http://www.quake.utah.edu>*. The contact person for data requests is Susan J. Nava, Network Manager, tel: (801) 581-6274; e-mail: *nava@seis.utah.edu*.

REFERENCES CITED

Arabasz, W. J. (2002a). FY 2003 ANSS Implementation Plan—Intermountain West (IMW) Region, (part of National Implementation Plan for an Advanced National Seismic System), *<www.seis.utah.edu/ anss/imw-fy03plan.pdf>*, 15 p.

Arabasz, W.J. (2002b). FY 2002 ANSS Activities in the Intermountain West Region, *<www.seis.utah.edu/anss/imw_2002oct11.shtml>*.

Arabasz, W. J., S. J. Nava, M. K. McCarter, and K. L. Pankow (2002c). Ground-motion recording and analysis of mining-induced seismicity in the Trial Mountain area, Emery County, Utah: Technical Report to State of Utah School and Trust Lands Administration, University of Utah Seismograph Stations, Salt Lake City, Utah, 28 p. plus 5 tables, 22 figs. and 6 appendices.

Arabasz, W. J., J. Ake, M. K. McCarter, and A. McGarr (2002d). Mining-induced seismicity near Joes Valley Dam: Summary of ground-motion studies and assessment of probable maximum magnitude (2002e). Technical Report to State of Utah School and Trust Lands Administration, University of Utah Seismograph Stations, Salt Lake City, Utah, 19 p. plus 4 tables and 11 figs.

Arabasz, W. J., J. Ake, M. K. McCarter, A. McGarr, S. J. Nava, and K. L. Pankow (2002e). Coal-mining seismicity in the Trail Mountain area, Utah: Part I—Case study for assessing ground-shaking hazard [abs.]: *Eos, Trans. Am. Geophys. Union* **83** (47), Fall Meet. Suppl., S12A-1170, F1051.

Black, B. D., W. R. Lund, and B. H. Mayes (1995). Summary of new information from the South Fork Dry Creek site, Salt Lake County, Utah, in *Environmental and Engineering Geology of the Wasatch Front Region*, W. R. Lund, editor, *Utah Geol. Assoc. Publ. 24*, 11-30.

Frankel, A., C. Mueller, T. Barnhard, D. Perkins, E. V. Leyendecker, N. Dickman, S. Hanson, and M.

Hopper (1996). National Seismic Hazard Maps: Documentation June 1996, *U.S. Geol. Surv. Open-File Rept. 96-532*.

FEMA (2000). *HAZUS 99 Estimated Annualized Earthquake Losses for the United States*, Federal Emergency Management Agency, *FEMA 366*, Washington, DC, 32 pp.

Machette, M. N., S. F. Personius, A. R. Nelson, and D. P. Schwartz (1991). The Wasatch fault zone, Utah—segmentation and history of Holocene earthquakes, *J. Struct. Geol*. **13** (2), 137-149.

McCalpin, J. P. and C. V. Nelson (2000). Long recurrence records from the Wasatch fault zone, Utah, Final Technical Report, Contract 99HQGR0058, National Earthquake Hazards Reduction Program, U.S. Geological Survey, 61 pp.

McCalpin, J. P. and S. P. Nishenko (1996). Holocene paleoseismicity, temporal clustering, and probabilities of future large (M>7) earthquakes on the Wasatch fault zone, Utah, *J. Geophys. Res*. **101** (B3), 6233-6253.

Pankow, K. L., J. C. Pechmann, S. J. Nava, and W. J. Arabasz (2002a). Utah's new ANSS urban strong-motion network around the Wasatch fault [abs.]: *Seismological Research Letters* **73** (2), 265.

Pankow, K. L., S. J. Nava, J. C. Pechmann, and W. J. Arabasz (2002b). Triggered seismicity in Utah from the November 3, 2002, Denali Fault Earthquake [abs.]: *Eos, Trans. Am. Geophys. Union* **83** (47), Fall Meet. Suppl., S72F-1359, (Late Breaking Session, p. 9).

Pankow, K. L., W. J. Arabasz, S. J. Nava, and J. C. Pechmann (2003). Triggered seismicity in Utah from the November 3, 2002, Denali Fault earthquake, *Survey Notes* **35** (1) (Utah Geological Survey, Salt Lake City), 11-12.

Rojahn, C., S. A. King, R. E. Scholl, A. S. Kiremidjian, L. D. Reaveley, and R. R. Wilson (1997). Earthquake damage and loss estimation methodology and data for Salt Lake County, Utah (ATC-36), *Earthquake Spectra* **13** (4), 623-642.

Spudich, P., W. B. Joyner, A. G. Lindh, D. M. Boore, B. M. Margaris, and J. B. Fletcher (1999). SEA99: A revised ground motion prediction relation for use in extensional tectonic regimes, *Bull. Seism. Soc. Am.* **89**, 1156-1170.

Waldhauser, F. (2001). hypoDD—A program to compute double-difference hypocenter locations, *U.S. Geol. Survey Open-File Rept 01-113*, 25 pp.

Waldhauser, F. and W L. Ellsworth (2000). A double-difference earthquake location algorithm: Method and application to the northern Hayward Fault, California, *Bull. Seism. Soc. Am.* **90**, 1353-1368.

REPORTS AND PUBLICATIONS

Arabasz, W. J. (2002a). FY 2003 ANSS Implementation Plan—Intermountain West (IMW) Region, (part of National Implementation Plan for an Advanced National Seismic System), <*www.seis.utah.edu/ anss/imw-fy03plan.pdf*>, 15 p.

Arabasz, W.J. (2002b). FY 2002 ANSS Activities in the Intermountain West Region, <*www.seis.utah.edu/anss/imw_2002oct11.shtml*>.

Arabasz, W. J., S. J. Nava, M. K. McCarter, and K. L. Pankow (2002c). Ground-motion recording and analysis of mining-induced seismicity in the Trial Mountain area, Emery County, Utah: Technical Report to State of Utah School and Trust Lands Administration, University of Utah Seismograph Stations, Salt Lake City, Utah, 28 p. plus 5 tables, 22 figs. and 6 appendices.

Arabasz, W. J., J. Ake, M. K. McCarter, and A. McGarr (2002d). Mining-induced seismicity near Joes Valley Dam: Summary of ground-motion studies and assessment of probable maximum magnitude (2002e). Technical Report to State of Utah School and Trust Lands Administration, University of Utah Seismograph Stations, Salt Lake City, Utah, 19 p. plus 4 tables and 11 figs.

Arabasz, W. J., J. Ake, M. K. McCarter, A. McGarr, S. J. Nava, and K. L. Pankow (2002e). Coal-mining seismicity in the Trail Mountain area, Utah: Part I—Case study for assessing ground-shaking hazard [abs.]: *Eos, Trans. Am. Geophys. Union* **83** (47), Fall Meet. Suppl., S12A-1170, F1051.

Nava, S. J. (2001, 2002). Earthquake activity in the Utah region [summaries and maps of seismicity in the Utah region, published quarterly by the Utah Division of Emergency Services and Homeland Security in *Fault Line Forum*].

Pankow, K. L., J. C. Pechmann, S. J. Nava, and W. J. Arabasz (2002a). Utah's new ANSS urban strong-motion network around the Wasatch fault [abs.]: *Seismological Research Letters* **73** (2), 265.

Pankow, K. L., S. J. Nava, J. C. Pechmann, and W. J. Arabasz (2002b). Triggered seismicity in Utah from the November 3, 2002, Denali Fault Earthquake [abs.]: *Eos, Trans. Am. Geophys. Union* **83** (47), Fall Meet. Suppl., S72F-1359, (Late Breaking Session, p. 9).

APPENDIX A

Station Information for University of Utah Regional/Urban Seismic Network
December 31, 2002

TABLE A-1
UNIVERSITY OF UTAH REGIONAL/URBAN SEISMIC NETWORK
Operating Seismograph Stations
December 31, 2002

UURSN Code	Location	SEED Station	SEED Channel	No. of Channels	Network Code	Latitude	Longitude	Elevation (meters)	Sensor	Digitizer	Telemetry	Sponsor
7208	SR 201/I-80 Bridge Array, Salt Lake City, UT	7208	EN[ZEN]	3	NP	40° 43.38'	111° 54.43'	1291	EpiSensor	K2	Digital	NSMP
7212	Annex Bldg., Weber State University, Ogden, UT	7212	HN[ZEN]	3	NP	41° 11.76'	111° 56.50'	1422	EpiSensor	K2	Digital	NSMP
AHI	Auburn, ID	AHID	BH[ZEN]	3	US	42° 45.92'	111° 06.02'	1960	*	*	Digital	USGS
ALP	Alpine Fire Station, Alpine, UT	ALP	EN[ZEN]	3	UU	40° 27.27'	111° 46.61'	1510	EpiSensor	K2	Digital	ANSS
ALT	Alta City Offices, Alta, UT	ALT	EN[ZEN]	3	UU	40° 35.42'	111° 38.25'	2635	Applied Mems	ANSS-130	Digital	ANSS
AMF	Tri-Cities Golf Course American Fork, UT	AMF	EN[ZEN]	3	UU	40° 24.12'	111° 47.28'	1445	EpiSensor	K2	Digital	ANSS
ANMO	Albuquerque, NM	ANMO	BH[ZEN]	3	IU	39° 56.77'	106° 27.40'	1740	*	*	Digital	USGS
ARUT	Antelope Range, UT	ARUT	EHZ	1	UU	37° 47.28'	113° 26.42'	1646	L4C	Masscomp	Analog	Utah
AVE	Avenues, Salt Lake City, UT	AVE	EN[ZEN]	3	UU	40° 46.47'	111° 51.77'	1387	Applied Mems	ANSS-130	Digital	ANSS
BBU	Bumble Bee, Salt Lake City, UT	BBU	EH[ZEN]	3	UU	40° 44.73'	112° 00.67'	1291	L4C	Masscomp	Analog	USGS
BCS	Brigham City Maintenance Shop Brigham City, UT	BCS	EN[ZEN]	3	UU	40° 30.71’	112° 01.98'	1303	EpiSensor	K2	Digital	ANSS
BCU	Brigham City, UT	BCU	EN[ZEN]	3	UU	41° 30.74'	111° 58.93'	1676	EpiSensor	K2	Digital	ANSS
BEA	Beaver Mountain, WY	BEAW	EHZ	1	RE	43° 15.06'	110° 36.80'	2960	*	*	Analog	USBR
BEI	Bear River Range, ID	BEI	EHZ	1	UU	42° 07.00'	111° 46.94'	1859	L4C	Masscomp	Analog	USGS
BES	Bates Elementary School Ogden, UT	BES	EN[ZEN]	3	UU	42° 19.10'	111° 57.26'	1455	EpiSensor	K2	Digital	ANSS
BGMT	Barton Gulch, MT	BGMT	EHZ	1	MB	45° 14.00'	112° 02.43'	2172	*	*	Analog	MBMT
BGU	Big Grassy Mountain, UT	BGU	EN[ZEN] HH[ZEN]	3 3	UU	40° 55.25'	113° 01.79'	1640	Episensor 40T	72A-08	Digital	ANSS
BHU	Blowhard Mountain, UT	BHU	EH[ZEN]	3	UU	37° 35.55'	112° 51.42'	3230	S13	Masscomp	Analog	Utah
BMN	Battle Mountain, NM	BMN	BHZ	1	NN	40° 25.89'	117° 13.31'	1594	*	*	Digital	UNR
BMUT	Black Mountain, UT	BMUT	EHZ	1	UU	41° 57.49'	111° 14.05'	2243	S13	Masscomp	Analog	USGS
BON	Boundary Peak, NV	BONR	SHZ	1	NN	37° 57.31'	118° 18.10'	2582	*	*	Digital	UNR
BOZ	Bozeman, MT	BOZ	BH[ZEN]	3	US	45° 38.82'	111° 37.78'	1589	*	*	Digital	USGS
BSS	Butlerville Substation Salt Lake City, UT	BSS	EN[ZEN]	3	UU	40° 37.45'	111° 49.34'	1451	EpiSensor	K2	Digital	ANSS

UURSN Code	Location	SEED Station	SEED Channel	No. of Channels	Network Code	Latitude	Longitude	Elevation (meters)	Sensor	Digitizer	Telemetry	Sponsor
BTU	Barney Top, UT	BTU	EHZ	1	UU	37° 45.34'	111° 52.46'	3235	S13	Masscomp	Analog	Utah
BW0	Boulder, WY	BW06	BH[ZEN]	3	US	42° 46.00'	109° 33.50'	2224	*	*	Digital	USGS
BYP	Brigham Young Park Salt Lake City, UT	BYP	EN[ZEN]	3	UU	40° 46.27'	111° 53.23'	1328	Applied Mems	ANSS-130	Digital	ANSS
BYU	Brigham Young University Provo, UT	BYU	EN[ZEN]	3	UU	40° 15.19'	111° 38.95'	1421	EpiSensor	K2	Digital	ANSS
BZMT	Bozeman Pass, MT	BZMT	EHZ	1	MB	45° 38.89'	110° 47.80'	2172	*	*	Analog	MBMT
CFS	Copperton Fire Station Copperton, UT	CFS	EN[ZEN]	3	UU	40° 33.94'	112° 05.61'	1654	EpiSensor	K2	Digital	ANSS
CHS	Copper Hills High School, West Jordan, UT	CHS	EN[ZEN]	3	UU	40° 35.68'	112° 01.03'	1460	Applied Mems	ANSS-130	Digital	ANSS
COM	Craters of the Moon, ID	COMI	EHZ	1	IE	43° 27.72'	113° 35.64'	1890	*	*	Analog	INEEL
CTU	Camp Tracy, UT	CTU	HH[ZEN]	3	UU	40° 41.55'	111° 45.02'	1731	40T	72A-07	Digital	USGS
CWU	Camp Williams, UT	CWU	EHZ	1	UU	40° 26.75'	112° 06.13'	1945	L4C	Masscomp	Analog	USGS
DAU	Daniels Canyon, UT	DAU	EHZ	1	UU	40° 24.75'	111° 15.35'	2771	S13	Masscomp	Analog	USGS
DBD	Des Bee Dove, UT	DBD	EHZ	1	UU	39° 18.82'	111° 05.55'	2265	L4C	Masscomp	Analog	Utah
DCU	Deer Creek Reservoir, UT	DCU	EHZ	1	UU	40° 24.82'	111° 31.61'	1829	L4C	Masscomp	Analog	USGS
DOT	Utah Dept. of Transportation Region II Offices, Salt Lake City, UT	DOT	EN[ZEN]	3	UU	40° 43.60'	111° 46.61'	1292	Applied Mems	ANSS-130	Digital	ANSS
DUG	Dugway, UT	DUG	BH[ZEN]	3	US	40° 11.70'	112° 48.80'	1477	*	*	Digital	USGS
			EH[ZEN] EL[ZEN]	6	UU				S13	Masscomp	Analog	Utah, USGS
DWU	Dry Willow, UT	DWU	EHZ	1	UU	38° 06.32'	112° 59.85'	2270	S13	Masscomp	Analog	Utah
ECR	Eagle Creek, ID	ECRI	EHZ	1	IE	43° 03.24'	111° 22.26'	2086	*	*	Analog	INEEL
EKU	East Kanab, UT	EKU	EHZ	1	UU	37° 04.48'	112° 29.81'	1829	S13	Masscomp	Analog	Utah
ELE	East Layton Elementary School, East Layton, UT	ELE	EN[ZEN]	3	UU	41° 04.83'	111° 55.08'	1450	Applied Mems	ANSS-130	Digital	ANSS
ELK	Elko, NV	ELK	BH[ZEN]	3	US	40° 44.69'	115° 14.33'	2210	*	*	Digital	USGS
ELU	Electric Lake, UT	ELU	EHZ	1	UU	39° 38.41'	111° 12.23'	2970	L4C	Masscomp	Analog	Utah
EMU	Emma Park, UT	EMU	EH[ZEN] ELZ	4	UU	39° 48.84'	110° 48.92'	2268	S13	Masscomp	Analog	USGS
			EN[ZEN]	3					FBA23	K2	None	Utah
EPU	East Promontory, UT	EPU	EHZ	1	UU	41° 23.49'	112° 24.53'	1436	L4C	Masscomp	Analog	USGS
ETW	Elwood Town Hall, Elwood, UT	ETW	EN[ZEN]	3	UU	41° 40/17'	112° 08.63'	1305	Applied Mems	ANSS-130	Digital	ANSS
FLU	Fool’s Peak, UT	FLU	EHZ	1	UU	39° 22.69'	112° 10.29'	1951	18300	Masscomp	Analog	USGS

UURSN Code	Location	SEED Station	SEED Channel	No. of Channels	Network Code	Latitude	Longitude	Elevation (meters)	Sensor	Digitizer	Telemetry	Sponsor
FPU	Francis Peak, UT	FPU	EHZ	1	UU	41° 01.58'	111° 50.21'	2816	L4C	Masscomp	Analog	USGS
FSU	Fish Springs, UT	FSU	EHZ	1	UU	39° 43.35'	113° 23.48'	1487	18300	Masscomp	Analog	Utah
FTT	Fire Training Tower, Magna, UT	FTT	EN[ZEN]	3	UU	40° 41.17'	112° 05.00'	1381	Applied Mems	ANSS-130	Digital	ANSS
GAS	PacifiCorp Gassification Plant, Salt Lake City, UT	GAS	EN[ZEN]	3	UU	40° 46.18'	111° 54.42'	1294	Applied Mems	ANSS-130	Digital	ANSS
GBI	Big Grassy Butte, ID	GBI	EHZ	1	IE	43° 59.22'	112° 03.78'	1541	*	*	Analog	INEEL
GCMT	Greycliff, MT	GCMT	EHZ	1	MB	45° 47.47'	109° 40.03'	1530	*	*	Analog	MBMT
GMO	Grantsville Maintenance Office, Grantsville, UT	GMO	EN[ZEN]	3	UU	40° 36.03'	112° 28.48'	1320	Applied Mems	ANSS-130	Digital	ANSS
GMU	Granite Mountain, UT	GMU	EH[ZEN] ELZ	4	UU	40° 34.53'	111° 45.79'	1829	S13	Masscomp	Analog	USGS
GMV	Granite Mountain Vault Sandy, UT	GMV	EN[ZEN]	3	UU	40° 34.40'	111° 45.79'	1829	EpiSensor	K2	Digital	ANSS
GRD	Gardner Farm, UT	GRD	EHZ	1	UU	40° 35.90'	111° 55.55'	1323	Ranger	Masscomp	Analog	USGS
GRR	Grays Lake, ID	GRRI	EHZ	1	IE	42° 56.28'	111° 25.32'	2207	*	*	Analog	INEEL
GZU	Grizzly Peak, UT	GZU	EH[ZEN] ELZ	4	UU	41° 25.53'	111° 58.50'	2646	S13	Masscomp	Analog	USGS
HCO	Holladay City Offices Holladay, UT	HCO	EN[ZEN]	3	UU	40° 40.08'	111° 49.39'	1362	EpiSensor	K2	Digital	ANSS
HDU	Hyde Park, UT	HDU	EHZ	1	UU	41° 48.27'	111° 45.89'	1853	L4C	Masscomp	Analog	USGS
HER	Herriman Fire Station Herriman, UT	HER	EN[ZEN]	3	UU	40° 30.94'	112° 01.85'	1502	EpiSensor	K2	Digital	ANSS
HES	Hooper Elementary School Hooper, UT	HES	EN[ZEN]	3	UU	41° 09.89'	112° 07.30'	1292	EpiSensor	K2	Digital	ANSS
HHA	Hell's Half Acre, ID	HHAI	EHZ	1	IE	43° 17.70'	112° 22.74'	1371	*	*	Analog	INEEL
HLI	Hailey, ID	HLID	BH[ZEN]	3	US	43° 33.75'	114° 24.83'	1772	*	*	Digital	USGS
HLJ	Hailstone, UT	HLJ	EH[ZEN] EN[ZEN]	3 3	UU	40° 36.63'	111° 24.04'	1931	S13 FBA23	Masscomp K2	Analog None	Utah
HON	Honeyville, UT	HON	EN[ZEN]	3	UU	41° 36.96'	112° 03.05'	1546	Applied Mems	ANSS-130	Digital	ANSS
HONU	Honeyville, UT	HONU	EHZ	1	UU	41° 36.90'	112° 03.00'	1515	L4C	Masscomp	Analog	USGS
HRU	Hogsback Ridge, UT	HRU	EHZ	1	UU	40° 47.17'	111° 53.09'	1640	Ranger	Masscomp	Analog	USGS
HTU	Hoyt, UT	HTU	EHZ	1	UU	40° 40.52'	111° 13.21'	2576	L4C	Masscomp	Analog	USGS
HVU	Hansel Valley, UT	HVU	HH[ZEN]	3	UU	41° 46.78'	112° 46.50'	1609	40T	72A-07	Digital	USGS
HWU	Hardware Ranch, UT	HWUT	BH[ZEN]	3	US	41° 36.41'	111° 33.91'	1830	*	*	Digital	USGS
ICF	International Center Fire Station Salt Lake City, UT	ICF	EN[ZEN]	3	UU	40° 46.68'	112° 01.69'	1281	EpiSensor	K2	Digital	ANSS

UURSN Code	Location	SEED Station	SEED Channel	No. of Channels	Network Code	Latitude	Longitude	Elevation (meters)	Sensor	Digitizer	Telemetry	Sponsor
ICU	Indian Springs Canyon, UT	ICU	EHZ	1	UU	37° 08.98'	113° 55.41'	1451	S13	Masscomp	Analog	Utah
IMU	Iron Mountain, UT	IMU	EHZ	1	UU	38° 37.99'	113° 09.50'	1833	L4C	Masscomp	Analog	Utah
IMW	Indian Meadows, WY	IMW	EHZ	1	RC	43° 53.82'	110° 56.34'	2646	*	*	Analog	BYU-I
JLU	Jordanelle, UT	JLU	EN[ZEN] HH[ZEN]	3 3	UU	40° 36.12'	111° 27.00'	2285	EpiSensor 3ESP	72A-08	Digital	ANSS
JRP	Jordan River State Park Salt Lake City, UT	JRP	EN[ZEN]	3	UU	40° 49.54'	111° 56.66'	1284	EpiSensor	K2	Digital	ANSS
JVW	Jordan Valley Water District Well, Murray, UT	JVW	EN[ZEN]	3	UU	40° 37.95'	111° 54.47'	1315	Applied Mems	ANSS-130	Digital	ANSS
KLJ	Keetley, UT	KLJ	EHZ	1	UU	40° 37.85'	111° 24.30'	1992	S13	Masscomp	Analog	Utah
KNB	Kanab, UT	KNB	BH[ZEN]	3	US	37° 01.00'	112° 49.34'	1715	*	*	Digital	LLNL
LDJ	Lady, UT	LDJ	EHZ	1	UU	40° 34.89'	111° 24.52'	2217	S13	Masscomp	Analog	Utah
LEVU	Levan, UT	LEVU	EHZ	1	UU	39° 30.39'	111° 48.88'	1996	L4C	Masscomp	Analog	USGS
LGC	Lakeside Golf Course Bountiful, UT	LGC	EN[ZEN]	3	UU	40° 54.04'	111° 54.51'	1292	EpiSensor	K2	Digital	ANSS
LKC	Lee Kay Hunter Education Center Magna, UT	LKC	EN[ZEN]	3	UU	40° 43.72'	112° 02.15'	1289	EpiSensor	K2	Digital	ANSS
LKW	Lake, WY	LKWY	BH[ZEN]	3	US	44° 33.91'	110° 24.00'	2424	*	*	Digital	USGS
LMU	Lake Mountain, UT	LMU	EN[ZEN]	3	UU	40° 18.91'	111° 55.92'	1593	EpiSensor	K2	Digital	ANSS
LOH	Long Hollow, WY	LOHW	EHZ	1	RE	43° 36.75'	110° 36.23'	2121	*	*	Analog	USBR
LRG	Logan River Golf Course	LRG	EN[ZEN]	3	UU	41° 42.82'	111° 51.08'	1362	Applied Mems	ANSS-130	Digital	ANSS
LSU	Lake Shores, UT	LSU	EN[ZEN]	3	UU	40° 07.94'	111° 43.81'	1375	EpiSensor	K2	Digital	ANSS
LTU	Little Mountain, UT	LTU	EHZ	1	UU	41° 35.51'	112° 14.83'	1585	L4C	Masscomp	Analog	USGS
MAB	Mapleton Ambulance Building Mapleton, UT	MAB	EN[ZEN]	3	UU	41° 07.79'	111° 34.67'	1440	EpiSensor	K2	Digital	ANSS
MCID	Moose Creek, ID	MCID	EHZ	1	WY	44° 11.42'	111° 10.96'	2149	L4C	Masscomp	Analog	USGS
MCU	Monte Cristo Peak, UT	MCU	EHZ	1	UU	41° 27.70'	111° 30.45'	2664	18300	Masscomp	Analog	USGS
MGU	Meadow Brook Golf Course Salt Lake City, UT	MGU	EHZ	1	UU	40° 40.89'	111° 55.09'	1291	Ranger	Masscomp	Analog	USGS
MHD	Mile High Drive, UT	MHD	EHZ	1	UU	40° 39.64'	111° 48.05'	1597	Ranger	Masscomp	Analog	USGS
MID	Middle Canyon, UT	MID	EN[ZEN]	3	UU	40° 31.04'	112° 15.28'	1722	Applied Mems	ANSS-130	Digital	ANSS
MLI	Malad Range, ID	MLI	EHZ	1	UU	42° 01.61'	112° 07.53'	1896	L4C	Masscomp	Analog	USGS
MMU	Miners Mountain, UT	MMU	EHZ	1	UU	38° 11.91'	111° 17.66'	2387	S13	Masscomp	Analog	Utah
MOMT	Monida, MT	MOMT	EHZ	1	MB	44° 35.60'	112° 23.66'	2220	*	*	Analog	MBMT
MOUT	Mount Ogden, UT	MOUT	EHZ	1	UU	41° 11.94'	111° 52.73'	2743	S13	Masscomp	Analog	USGS

UURSN Code	Location	SEED Station	SEED Channel	No. of Channels	Network Code	Latitude	Longitude	Elevation (meters)	Sensor	Digitizer	Telemetry	Sponsor
MPU	Maple Canyon, UT	MPU	EN[ZEN]	3	UU	40° 00.93'	111° 38.00'	1909	EpiSensor	K2	Digital	ANSS
			HH[ZEN]	3					40T	72A-07	Digital	USGS
MSU	Marysvale, UT	MSU	EHZ	1	UU	38°30.74'	112° 10.63'	2105	18300	Masscomp	Analog	Utah
MTUT	Morton Thiokol, UT	MTUT	EHZ	1	UU	41° 42.55	112° 27.28'	1373	L4C	Masscomp	Analog	USGS
MVU	Marysvale, UT	MVU	BH[ZEN]	3	LB	38° 30.22'	112° 12.74'	2240	*	*	Digital	Sandia
NAI	North Antelope Island, UT	NAI	EN[ZEN]	3	UU	41° 00.97'	112° 13.68'	1472	EpiSensor	K2	Digital	ANSS
NAIU		NAIU	EHZ	1					L4C	Masscomp	Analog	USGS
NLU	North Lily Mine, UT	NLU	EN[ZEN]	3	UU	39° 57.29'	112° 04.50'	2036	3ESP	72A-08	Digital	ANSS
			HH[ZEN]	3					EpiSensor			
NMU	North Mineral Mountain, UT	NMU	EH[ZEN] ELZ	4	UU	38° 30.99'	112° 51.00'	1853	S13	Masscomp	Analog	Utah
NOQ	North Oquirrh Mountains, UT	NOQ	EN[ZEN]	3	UU	40° 39.15'	112° 07.22'	1622	EpiSensor	K2	Digital	ANSS
			HH[ZEN]	3					40T	72A-07	Digital	USGS
NPI	North Pocatello, ID	NPI	EHZ	1	UU	42° 08.84'	112° 31.10'	1640	L4C	Masscomp	Analog	USGS
OCP	Orem City Park, Orem, UT	OCP	EN[ZEN]	3	UU	40° 17.88'	111° 41.44'	1464	EpiSensor	K2	Digital	ANSS
OF2	Ogden Fire Station #2 Ogden, UT	OF2	EN[ZEN]	3	UU	41° 13.70'	111° 56.92'	1358	EpiSensor	K2	Digital	ANSS
OWUT	Old Woman Plateau, UT	OWUT	EHZ	1	UU	38° 46.80'	111° 25.42'	2568	L4C	Masscomp	Analog	Utah
P03	Wild Steer, Paradox Basin, CO	PV03	EHZ	1	RE	38° 15.26'	108° 50.88'	1975	*	*	Analog	USBR
P15	Potato Mountain Paradox Basin, CO	PV15	EHZ	1	RE	38° 20.51'	108° 28.86'	2280	*	*	Analog	USBR
PCR	Park City Recreation Center Park City, UT	PCR	EN[ZEN]	3	UU	40° 39.26'	111° 30.20'	2100	EpiSensor	K2	Digital	ANSS
PGC	Pleasant Grove Creek, UT	PGC	EN[ZEN]	3	UU	40° 22.72'	111° 42.61'	1707	EpiSensor	K2	Digital	ANSS
PRN	Pahroc, Range, NV	PRN	SHZ	1	NN	37° 24.40'	115° 03.05'	1402	*	*	Digital	UNR
PTU	Portage, UT	PTU	EHZ	1	UU	41° 55.76'	112° 22.21'	1670	L4C	Masscomp	Analog	USGS
QLMT	Earthquake Lake, MT	QLMT	EHZ	1	MB	44° 49.90'	111° 25.65'	2012	*	*	Analog	MBMT
RBU	Red Butte Canyon, UT	RBU	EHZ	1	UU	40° 46.85'	111° 48.50'	1676	L4C	Masscomp	Analog	USGS
RCJ	Ross Creek, UT	RCJ	EHZ	1	UU	40° 39.51'	111° 26.36'	2090	S13	Masscomp	Analog	Utah
RIV	Public Works Building Riverton, UT	RIV	EN[ZEN]	3	UU	40° 31.15'	111° 56.06'	1347	EpiSensor	K2	Digital	ANSS
RSUT	Red Spur, UT	RSUT	EHZ	1	UU	41° 38.31'	111° 25.90'	2682	S13	Masscomp	Analog	USGS
SAIU	South Antelope Island, UT	SAIU	EHZ	1	UU	40° 51.29'	112° 10.89'	1384	L4C	Masscomp	Analog	USGS
SCC	Salt Lake Community College Salt Lake City, UT	SCC	EN[ZEN]	3	UU	40° 40.49'	111° 56.37'	1306	EpiSensor	K2	Digital	ANSS
SCS	Syracuse City Cemetery Shop Syracuse, UT	SCS	EN[ZEN]	3	UU	41° 05.73'	112° 02.81'	1321	EpiSensor	K2	Digital	ANSS
SCY	Salem City Yard, Salem, UT	SCY	EN[ZEN]	3	UU	40° 03.47'	111° 41.13'	1386	Applied	ANSS-130	Digital	ANSS

UURSN Code	Location	SEED Station	SEED Channel	No. of Channels	Network Code	Latitude	Longitude	Elevation (meters)	Sensor	Digitizer	Telemetry	Sponsor
									Mems			
SGU	Sterling, UT	SGU	EHZ	1	UU	39° 10.94'	111° 38.68'	2357	18300	Masscomp	Analog	USGS
SHP	Sheep Range, NV	SHP	EHZ	1	NN	36° 30.33'	115° 09.61'	1590	*	*	Digital	UNR
SJF	South Jordan Fire Station, South Jordan, UT	SJF	EN[ZEN]	3	UU	40° 33.37'	111° 56.33'	1356	Applied Mems	ANSS-130	Digital	ANSS
SLC	University of Utah WBB Bldg. Salt Lake City, UT	SLC	EL[EN]	2	UU	40° 45.97'	111° 50.86'	1436	WA Sim	Masscomp	Hardwired	USGS
			EN[ZEN]	3					FBA23	Masscomp		
SNO	Snow College, UT	SNO	EHZ	1	UU	39° 19.18'	111° 32.33'	2503	Ranger	Masscomp	Analog	Utah
SNUT	Stanbury North, UT	SNUT	EHZ	1	UU	40° 53.14'	112° 30.54'	1652	18300	Masscomp	Analog	USGS
SPR	Wildlife Resource Center Springville, UT	SPR	EN[ZEN]	3	UU	40° 10.99'	111° 36.68'	1379	EpiSensor	K2	Digital	ANSS
SPU	South Promontory Point, UT	SPU	EN[ZEN]	3	UU	41° 18.52'	112° 26.95'	2086	EpiSensor	72A-08	Digital	ANSS
			HH[ZEN]	3					3ESP			
SRU	San Rafael Swell, UT	SRU	EHZ	1	UU	39° 06.65'	110° 31.43'	1804	S13	Masscomp	Analog	Utah
			HH[ZEN]	6					3T	72A-08	Digital	
			EN[ZEN]						EpiSensor			
SSC	Sandy Senior Center Sandy, UT	SSC	EN[ZEN]	3	UU	40° 34.89'	111° 51.35'	1414	EpiSensor	K2	Digital	ANSS
SUU	Santaquin Canyon, UT	SUU	EHZ	1	UU	39° 53.29'	111° 47.45'	2024	18300	Masscomp	Analog	USGS
TCU	Toone Canyon, UT	TCU	EN[ZEN]	3	UU	41° 07.04'	111° 24.47'	2269	EpiSensor	72A-08	Digital	ANSS
			HH[ZEN]	3					3ESP			
TCUT	Toone Canyon, UT	TCUT	EHZ	1	UU	41° 07.07'	111° 24.51'	2320	L4C	Masscomp	Analog	USGS
TMI	Taylor Mountain, ID	TMI	EHZ	1	IE	43° 18.30'	111° 55.08'	2179	*	*	Analog	INEEL
TMU	Trail Mountain, UT	TMU	HH[ZEN]	3	UU	39° 17.79'	111° 12.49'	2731	40T	72A-08	Digital	Utah
TM2		TM2	EH[ZEN]	3					S13			
TPMT	Teepe Creek, MT	TPMT	EHZ	1	MB	44° 43.79'	111° 39.94'	2518	*	*	Analog	MBMT
TPNV	Topopah Spring, NV	TPNV	BH[ZEN]	3	US	36° 56.93'	116° 14.97'	1600	*	*	Digital	USGS
TPU	Thanksgiving Point, Lehi, UT	TPU	EN[ZEN]	3	UU	40° 25.81'	111° 54.13'	1383	EpiSensor	K2	Digital	ANSS
TRC	Troy Canyon, NV	TRC	BHZ	1	NN	38° 20.98'	115° 35.11'	1815	*	*	Digital	UNR
TRS	Tooele County Radio Shop, Tooele, UT	TRS	EN[ZEN]	3	UU	40° 30.83'	112° 18.63'	1568	EpiSensor	K2	Digital	ANSS
TUC	Tucson,AZ	TUC	BH[ZEN]	3	US	32° 18.58'	110°47.05'	906	*	*	Digital	USGS
UHP	Utah Highway Patrol Farmington, UT	UHP	EN[ZEN]	3	UU	40° 59.50'	111° 53.85'	1295	EpiSensor	K2	Digital	ANSS
UTH	Uintah Town Hall, Uintah, UT	UTH	EN[ZEN]	3	UU	41° 08.65'	111° 55.52'	1389	EpiSensor	K2	Digital	ANSS
UUE	University of Utah EMCB Bldg. Salt Lake City, UT	UUE	EN[ZEN]	3	UU	40° 46.11'	111° 50.78'	1449	EpiSensor	K2	Digital	ANSS

UURSN Code	Location	SEED Station	SEED Channel	No. of Channels	Network Code	Latitude	Longitude	Elevation (meters)	Sensor	Digitizer	Telemetry	Sponsor
VEC	Valley Emergency Communications Center West Valley City, UT	VEC	EN[ZEN]	3	UU	40° 43.47'	112° 01.93'	1455	EpiSensor	K2	Digital	ANSS
VES	Valley Elementary School, Huntsville, UT	VES	EN[ZEN]	3	UU	41° 15.72'	111° 46.13'	1501	Applied Mems	ANSS-130	Digital	ANSS
WBC	Weber Canyon, UT	WBC	EN[ZEN]	3	UU	41° 08.38'	111° 54.05'	1602	EpiSensor	K2	Digital	ANSS
WCF	Wellsville Fire Station, Wellsville, UT	WCF	EN[ZEN]	3	UU	41° 38.35'	111° 55.88'	1387	Applied Mems	ANSS-130	Digital	ANSS
WCN	Washoe, NV	WCN	HHZ	1	NN	39° 18.10'	119° 45.38'	1500	*	*	Digital	UNR
WCS	Willow Creek Coal Mine, UT	WCS	EN[ZEN]	3	UU	39° 44.03'	110° 51.03'	1912	FBA23	K2	None	Utah
WCU	Willow Creek, UT	WCU	EHZ	1	UU	38° 57.88'	112° 05.44'	2673	18300	Masscomp	Analog	USGS
WES	Westminster College Salt Lake City, UT	WES	EN[ZEN]	3	UU	40° 43.97'	111° 51.26'	1341	EpiSensor	K2	Digital	ANSS
WHS	West High School Salt Lake City, UT	WHS	EN[ZEN]	3	UU	40° 46.51'	111° 53.93'	1301	EpiSensor	K2	Digital	ANSS
WLJ	Wildlife, UT	WLJ	EHZ	1	UU	40° 36.80'	111° 20.68'	2075	S13	Masscomp	Analog	Utah
WMUT	West Mountain, UT	WMUT	EHZ	1	UU	40° 04.60'	111° 50.00'	1981	L4C	Masscomp	Analog	USGS
WRP	Water Reclamation Plant Salt Lake City, UT	WRP	EN[ZEN]	3	UU	40° 48.82'	111° 58.87'	1288	Applied Mems	ANSS-130	Digital	ANSS
WTU	Western Traverse Mountains, UT	WTU	EH[ZEN] ELZ	4	UU	40° 27.29'	111° 57.18'	1579	S13	Masscomp	Analog	USGS
			EN[ZEN]	3					Applied Mems	ANSS-130	Digital	ANSS
WUAZ	Wupatki, AZ	WUAZ	BH[ZEN]	3	US	35° 31.01'	111° 22.43'	1592	*	*	Digital	USGS
WVUT	Wellsville, UT	WVUT	EHZ	1	UU	41° 36.61'	111° 57.55'	1828	L4C	Masscomp	Analog	USGS
YCJ	Canyon Junction (YNP), WY	YCJ	EHZ	1	WY	44° 44.63'	110° 29.85'	2426	L4C	Masscomp	Analog	USGS
YDC	Denny Creek, MT	YDC	EHZ	1	WY	44° 42.57'	111° 14.38'	2025	L4C	Masscomp	Analog	USGS
YFT	Old Faithful (YNP), WY	YFT	HH[ZEN]	3	WY	44° 27.08'	110° 50.15'	2292	40T	72A-07	Digital	USGS
			EHZ	1					L4C	Masscomp	Analog	
YGC	Grayling Creek, MT	YGC	EHZ	1	WY	44° 47.77'	111° 06.39'	2075	L4C	Masscomp	Analog	USGS
YHB	Horse Butte, MT	YHB	EHZ	1	WY	44° 45.07'	111° 11.71'	2157	L4C	Masscomp	Analog	USGS
YHH	Holmes Hill (YNP), WY	YHH	EH[ZEN]	3	WY	44° 47.30'	110° 51.03'	2717	S13	Masscomp	Analog	USGS
YJC	Joseph's Coat (YNP), WY	YJC	EHZ	1	WY	44° 45.33'	110° 20.95'	2684	S13	Masscomp	Analog	USGS
YLA	Lake Butte (YNP), WY	YLA	EHZ	1	WY	44° 30.76'	110° 16.12'	2580	L4C	Masscomp	Analog	USGS
YLT	Little Thumb Creek (YNP), WY	YLT	EHZ	1	WY	44° 26.22'	110° 35.28'	2439	L4C	Masscomp	Analog	USGS
YMC	Maple Creek (YNP), WY	YMC	EHZ	1	WY	44° 45.56'	111° 00.37'	2073	L4C	Masscomp	Analog	USGS
YML	Mary Lake (YNP), WY	YML	EHZ	1	WY	44° 36.32'	110° 38.59'	2653	L4C	Masscomp	Analog	USGS

UURSN Code	Location	SEED Station	SEED Channel	No. of Channels	Network Code	Latitude	Longitude	Elevation (meters)	Sensor	Digitizer	Telemetry	Sponsor
YMP	Mirror Lake Plateau (YNP), WY	YMP	EH[ZEN]	3	WY	44° 44.41'	110° 09.36'	2774	S13	Masscomp	Analog	USGS
YMR	Madison River (YNP), WY	YMR	HH[ZEN]	3	WY	44° 40.12'	110° 57.90'	2149	40T	72A-07	Digital	USGS
YMS	Mount Sheridan (YNP), WY	YMS	EHZ	1	WY	44° 15.84'	110° 31.67'	3106	L4C	Masscomp	Analog	USGS
YMV	Mammoth Vault (YNP), WY	YMV	EHZ	1	WY	44° 58.42'	110° 41.33'	1829	L4C	Masscomp	Analog	USGS
YNR	Norris Junction (YNP), WY	YNR	EH[ZEN]	3	WY	44° 42.93'	110° 40.75'	2336	40T	Masscomp	Analog	USGS
YPC	Pelican Cone (YNP), WY	YPC	EHZ	1	WY	44° 38.88'	110° 11.55'	2932	L4C	Masscomp	Analog	USGS
YPM	Purple Mountain (YNP), WY	YPM	EHZ	1	WY	44° 39.43'	110° 52.12'	2582	L4C	Masscomp	Analog	USGS
YPP	Pitchstone Plateau (YNP), WY	YPP	EHZ	1	WY	44° 16.26'	110° 48.27'	2707	S13	Masscomp	Analog	USGS
YSB	Soda Butte (YNP), WY	YSB	EHZ	1	WY	44° 53.04'	110° 09.06'	2072	L4C	Masscomp	Analog	USGS
YTP	The Promontory (YNP), WY	YTP	EHZ	1	WY	44° 23.51'	110° 17.10'	2384	L4	Masscomp	Analog	USGS
YWB	West Boundary (YNP), WY	YWB	EHZ	1	WY	44° 36.35'	111° 06.05'	2310	L4C	Masscomp	Analog	USGS

* Indicates station operated by another agency and recorded as part of University of Utah regional seismic network
Network Statistics: 440 data channels from 190 stations were being recorded at the end of this report period
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EXPLANATION OF TABLE

UURSN Code: Station code used in routine processing. Due to processing software limitations, the station code may not be the station code used by the original operator.For multicomponent stations, the vertical, east-west, and north-south high gain (low gain) components are identified by an appended Z(V), E(L), and N(M), respectively.

Location: General description of station location. YNP = Yellowstone National Park.

SEED Station: The SEED (Standard for the Exchange of Earthquake Data) station code used by the original operator.SEED Channel: The SEED format uses three letters to name seismic channels. See <<http://www.iris.washington.edu/manuals/SEED_appA.html>> for information about the SEED channel naming convention. Relevant sections are reproduced below. In the SEED convention, each letter describes one aspect of the instrumentation and its digitization. The first letter specifies the general sampling rate and the response band of the instrument. Band codes used in this table include:

Band Code	Band Type	Sample Rate	Corner Period
E	Extremely short period	= 80 Hertz	< 10 seconds
H	High broadband	= 80 Hertz	= 10 seconds
B	Broadband	= 10 to < 80 Hertz	=10 seconds
S	Short period	= 10 to < 80 Hertz	< 10 seconds

The second letter specifies the family to which the sensor belongs. Sensor families used in this table are:

Instrument Code	Description
H	High gain seismometer
L	Low gain seismometer
N	Accelerometer

The third letter specifies the physical configuration of the members of a multiple axis instrument package. Channel orientations used in this table are:

Z E N Traditional (Vertical, East-West, North-South)

Number of Channels: Total number of waveform channels recorded.

Network Code: The FDSN (Federation of Digital Seismographic Networks) registered network code. See <<http://www.iris.washington.edu/FDSN/networks.txt>> for information about registered seismograph network codes. Network codes referenced in this table:

Network Code	Network name; Network operator or responsible organization
LB	Leo Brady Network; Sandia National Laboratory
IE	Idaho National Engineering and Environmental Laboratory
MB	Montana Regional Seismic Network; Montana Bureau of Mines and Geology
NN	Western Great Basin; University of Nevada, Reno
NP	National Strong Motion Program; U.S. Geological Survey
RC	Formerly Ricks College Network; Ricks College, Idaho; now BYU-Idaho

RE	U.S. Bureau of Reclamation Seismic Networks; U.S. Bureau of Reclamation, Denver Federal Center
UU	University of Utah Regional Network; University of Utah
US	US National Network; USGS National Earthquake Information Center
WY	Yellowstone Wyoming Seismic Network; University of Utah

Latitude, Longitude: Sensor location in degrees and decimal minutes; North latitude, West longitude.

Elevation: Sensor altitude in meters above sea level.

Sensor	**Description**
L4, L4C	Mark Products short-period seismometer
S13, 18300	Geotech S13 or 18300 short-period seismometer
Ranger	Kinemetrics Ranger short-period seismometer
40T	Guralp CMG-40T broadband seismometer
3T	Guralp CMG-3T broadband seismometer
3ESP	Guralp CMG-3ESP broadband seismometer
FBA23	Kinemetrics accelerometer
EpiSensor	Kinemetrics accelerometer
Applied Mems	Applied Mems accelerometer
WA Sim	Wood-Anderson displacement seismometer (electronically simulated)

Digitizer	**Description**
Masscomp	Concurrent Computer Corporation (formerly Masscomp) 7200C computer(with 12-bit digitizer)
K2	Kinemetrics Altus Series K2 (19-bit resolution field digitizer)
72A-07	Refraction Technology (REF TEK) model 72A-07 (24-bit field digitizer)
72A-08	Refraction Technology (REF TEK) model 72A-08 (24-bit field digitizer)
ANSS-130	Refraction Technology (REF TEK) model 130-ANSS/02 (24-bit resolution field digitizer)

Telemetry	**Description**
Analog	Data transmission is analog along part of the transmission pathway
Digital	Data are converted to digital form at the station site
Hardwired	Direct physical cable connection to computer recording system
None	On-site recording system

Sponsor (or Operator for stations marked by * in preceding columns)

USGS	U.S. Geological Survey
Utah	State of Utah
ANSS	Advanced National Seismic System
INEEL	Idaho National Engineering and Environmental Laboratory
USBR	U.S. Bureau of Reclamation
LLNL	Lawrence Livermore National Laboratory
Sandia	Sandia National Laboratory
BYU-I	Brigham Young University, Idaho (formerly Ricks College)

MBMT	Montana Bureau of Mines and Geology
NSMP	National Strong Motion Program, U.S. Geological Survey
UNR	University of Nevada, Reno

APPENDIX B

Addendum to SEA99: A New Peak Ground Velocity and Revised Peak Ground Acceleration and Pseudovelocity Predictive Relations for Extensional Tectonic Regimes

by Kris L. Pankow and James C. Pechmann
Univ. of Utah Seismograph Stations
Dept. of Geology and Geophysics
Salt Lake City, UT 84112

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Addendum to SEA99: A New Peak Ground Velocity and Revised Peak Ground Acceleration and Pseudovelocity Predictive Relations for Extensional Tectonic Regimes

Kris L. Pankow and James C. Pechmann

Abstract

In this note, we expand on a previous study of strong ground motions in extensional tectonic regimes by Spudich et al. (1999). First, we correct the predictive relations they determined for horizontal peak ground acceleration and 5%-damped pseudovelocity response for an approximately 20% overprediction of rock site data which they noted in their paper. Second, we regress data compiled in their study to determine a predictive relation for horizontal peak ground velocity. Peak ground velocity estimates are needed to apply some commonly-used methods for predicting earthquake damage and Modified Mercalli intensities. However, there are few other recently-published predictive relations for peak ground velocity–and none which are specifically designed for use in extensional tectonic regimes.

Introduction

Ground motion predictive relations ("attenuation relations") are a key element in deterministic and probabilistic seismic hazard analyses and in the seismic design of structures. Many different predictive relations have been published. These relations differ in the data sets and methods used to determine them, the earthquake strong ground motion parameters predicted, the functional forms of the equations, and the input parameters used for predicting the ground motions (see Abrahamson and Shedlock, 1997, for a review). Most recently-determined relations provide predictions for horizontal peak ground acceleration (PGA) and response spectral values–usually pseudovelocity (PSV) or pseudoacceleration (PSA). There are few recent predictive relations for peak ground velocity (PGV). However, PGV estimates are required in order to use some state-of-the-art methods for predicting earthquake damage (e.g., the HAZUS code, National Institute of Building Sciences, 1999a,b) and Modified Mercalli Intensities (e.g., Wald et al., 1999a, b).

One conclusion which can be drawn from comparing the various ground motion prediction relations available is that these relations vary with tectonic regime. Abrahamason and Shedlock (1997) divide predictive relations by tectonic regime into three categories, which are relations for: (1) subduction zone earthquakes, (2) shallow crustal earthquakes in stable continental regions, and (3) shallow crustal earthquakes in active tectonic regions. The third category is by far the most extensively studied–in part due to the large amount of strong motion data available from shallow crustal earthquakes in California. Several recent studies for category (3) earthquakes suggest that they should be further divided by faulting style – normal, strike-slip, and reverse (Abrahamson and Silva, 1997; Boore et al., 1997; Campbell, 1997; Sadigh et al., 1997) – or by more specific tectonic classification, e.g. extensional versus transpressional regimes (Spudich et al., 1996, 1999).

While there are a number of predictive relations appropriate for California, there are few which have been developed specifically for extensional regimes or normal faulting due to the relatively small amount of pertinent strong-motion data. Exceptions include the predictive relations determined by Spudich et al. (1996, 1997, 1999) using world-wide data from extensional regimes exclusively and the predictive relations of Abrahamson and Silva (1997), for which Abrahamson and Becker (1997) determined normal-faulting factors using the nine normal-faulting events in the Spudich et al. (1996) data set.

In order to use the ShakeMap code (Wald et al., 1999a) to compute near-real-time maps of ground motion in the Wasatch Front urban corridor of Utah, it is necessary to choose PGA, PGV, and 5%-damped PSA/PSV attenuation relations appropriate for this region. The Wasatch Front urban corridor is situated in an extensional tectonic regime on the eastern boundary of the Basin and Range province. The earthquakes which occur in this region have predominantly strike-slip and normal focal mechanisms (Bjarnason and Pechmann, 1989; Smith and Arabasz, 1991; Arabasz et al. 1992). The two most suitable sets of predictive relations available for use in this region are those of Abrahamson and Silva (1997; with the normal faulting factors of Abrahamson and Becker, 1997) and the "SEA99" extensional-regime relations of Spudich et al. (1999). However, there are practical limitations to using both of these sets of relations in ShakeMap. The most severe limitation is that neither one provides equations for PGV. The Abrahamson and Silva (1997) relations have the additional limitation of requiring specification of the earthquake focal mechanism, which is not always available quickly enough after an earthquake for ShakeMap purposes (within 10 minutes). As SEA99 does not require focal mechanism information, we decided to use SEA99 to generate ShakeMaps in the Wasatch Front region. However, Spudich et al. (1999) reported that "for rock sites SEA99 overestimates the data on average by about 0.08 $\log_{10}$ units or about 20%." Before using SEA99, we thought it was important to correct it for the reported 20% bias in rock site ground motion predictions. We also needed to find an appropriate PGV relation to use.

The purpose of this note is twofold: (1) to correct the SEA99 predictive relations for the rock site bias discussed in Spudich et al. (1999), and (2) to empirically derive a PGV predictive relation using the same data set and functional form as SEA99. By accomplishing these two goals we provide an improved version of SEA99 for rock sites, supplemented by a PGV relation for both rock and soil sites, for use in predicting ground motions in extensional tectonic regimes.

Correction for the Rock Site Bias in SEA99

SEA99 has the following functional form:

$$\log_{10}(Z) = b_1 + b_2 (\mathbf{M} - 6) + b_3 (\mathbf{M} - 6)^2 + b_5 \log_{10} D + b_6 \Gamma \quad (1)$$

where Z is the horizontal-component geometrical mean of either the peak ground acceleration (in g's) or the 5% damped pseudovelocity response (in cm/sec) at a particular period, **M** is the moment magnitude (Hanks and Kanomori, 1979),

$$D = (r_{jb}^2 + h^2)^{1/2}, \qquad (2)$$

and r_{jb} is the Joyner-Boore distance in km. The Joyner-Boore distance is the closest horizontal distance to the vertical projection of the fault rupture on the earth's surface (see Abrahamson and Shedlock, 1997, Figure 1). Γ is 0 for rock sites and 1 for soil sites, and b_1, b_2, b_3, b_5, b_6, and h are regression coefficients that depend on the ground motion parameter. Spudich et al. (1999) considered SEA99 to be valid in the moment magnitude range 5.0 to 7.7 and in the distance range 0 to 100 km.

In their analysis, Spudich et al. (1999) inverted for only b_1, b_5, and h. Citing a lack of extensional regime data at high magnitudes, they fixed the magnitude coefficients b_2 and b_3 to values determined by Boore et al. (1993, 1997). Similarly, due to the relatively small size of the SEA99 data set compared to that of Boore et al. (1993, 1994, 1997), they decided to calculate the soil coefficients b_6 using site amplification factors determined by Boore et al. (1994, 1997) as a function of average shear-wave velocity in the uppermost 30 meters (V_s30). Based on equation (1) of Boore et al., 1997, they assumed

$$b_6 = B_v (\log_{10} 310 - \log_{10} 620) \qquad (3)$$

where B_v is an empirically-determined factor from Boore et al. (1997, Table 8) and 620 m/sec and 310 m/sec are average V_s30 values for rock and soil sites, respectively, in western North America (primarily coastal California) from Boore and Joyner (1997). The SEA99 relations fit the soil data quite well at all periods. However, SEA99 overpredicts rock site ground motions by an average of 0.08 $\log_{10}$ units or 20% over the range of periods studied (Spudich et al., 1999, Figure 5).

Spudich et al. (1999) suggested that this rock site bias resulted from underestimating the average V_s30 for rock sites in extensional regimes and consequently overestimating the average ratios between rock and soil ground motions. This error would affect the rock site regressions much more than the soil site regressions because only 25% of the records in the SEA99 data set are from rock sites. Spudich et al. (1999) did not calculate how much faster ("harder") extensional regime rocks would have to be, on the average, to account for the rock site bias nor did they adjust their b_6 coefficients to eliminate this bias.

From (3), the average Vs30 of extensional regime rocks at sites in the SEA99 data set can be estimated from the rock site bias by solving the following equation for V_{rock}:

$$(V_{rock} /620)^{Bv} = 10^{-0.08} . \qquad (4)$$

The average B_v value for the 11 periods for which bias values are plotted in Figure 5a of Spudich et al. (1999) is -0.48. Substituting this value into equation (4) and solving yields V_{rock} = 910 m/sec. Analogous calculations for the specific ground motion parameters to be mapped by

ShakeMap–PGA and 5% damped PSV at 0.3, 1.0, and 2.0 sec period (instead of 3.0 sec, for which data are unavailable)–yield V_{rock} values of 914, 982, 788, and 945 m/sec, respectively, with a mean value of 907 m/sec. Our V_{rock} value of ~910 m/sec falls within the range of V_s30 values calculated by Ashland (2001) for Tertiary rocks at five sites in the Wasatch Front urban corridor–848 m/sec to 1245 m/sec–and is close to the geometrical mean value of 1023 m/sec.

Based on this new average near-surface rock velocity, we recalculated the b_6 coefficients using the following equation (modified from (3)):

$$b_6 = B_v (\log_{10} 310 - \log_{10} 910) \qquad (5)$$

where B_v is taken from Table 8 of Boore et al. (1997). Then, in order to correct for the rock site bias while leaving the predicted ground motions for soil sites unchanged, we adjusted the b_1 values using

$$b_1 = b_1^o + b_6^o - b_6 \qquad (6)$$

where the "o" superscripts indicate the SEA99 values reported in Table 2 of Spudich et al. (1999) and b_6 is from equation (5). The advantages of this method for correcting the rock bias are 1) the calculations are straightforward, 2) there are no changes to the soil predictive relations, which initially fit the data quite well, and 3) the frequency dependence of the soil coefficients is preserved through use of the B_v term. Corrected SEA99 coefficients for all periods are listed in Table 1.

The standard deviation of $\log_{10}(Z)$ is $\sigma_{\log Z}$, which Spudich et al. (1999) calculate using the following equation:

$$\sigma_{\log Z} = (\sigma_1^2 + \sigma_2^2)^{1/2}, \qquad (7)$$

where σ_1 and σ_2 are the standard deviations of the record-to-record variation and the earthquake-to-earthquake variation in the residuals. Table 2 of Spudich et al. (1999) lists the σ_1 and σ_2 values which they determined by applying the maximum likelihood method of Joyner and Boore (1993). Our correction for the rock site bias should reduce the variances of $\log_{10}(Z)$, $\sigma^2_{\log Z}$, by approximately 0.0016 – the fraction of rock measurements (0.25) multiplied by the squared difference in b_6 (~0.08^2). For PGA, the SEA99 $\sigma_{\log Z}$ value of 0.203 should be reduced to $((0.203)^2 - 0.25(0.174 - 0.112)^2)^{1/2} = 0.201$. As all of the reductions in $\sigma_{\log Z}$ are negligible compared to the errors in determining $\sigma_{\log Z}$, the $\sigma_{\log Z}$ values listed in Table 1 are uncorrected values calculated from σ_1 and σ_2 in Table 2 of Spudich et al. (1999) using (7). Table 1 also lists Spudich et al.'s values for σ_3 , which is the standard deviation of the difference between the log of a ground motion measurement from one horizontal component and the mean of the values from two orthogonal horizontal components (σ_c in Boore et al., 1997, equation 6). σ_3 is unaffected by our bias correction. It is used to calculate the standard deviation of the ground motion prediction for a randomly-oriented horizontal component, which is

$$\sigma_R = (\sigma^2_{\log Z} - \sigma_3^2)^{1/2} , \qquad (8)$$

To test our revised version of SEA99, we recalculated the PGA bias (mean residual) and $\sigma_{\log Z}$ using our new b_1 and b_6 coefficients and the PGA data and methodology used to derive SEA99. The bias in the rock regression for PGA was reduced from ~14% (-0.057 $\log_{10}$ units; Figure 5a, Spudich et al., 1999) to 1% (0.005 $\log_{10}$ units). $\sigma_{\log Z}$ was reduced to 0.199, in good agreement with the estimate above.

Peak Ground Velocity Regression

Spudich et al. (1996, 1999) collected PGV data in addition to PGA and PSV data.

However, they chose not to invert the former. Using the one-stage regression method of Joyner and Boore (1993, 1994) we inverted the PGV data set of Spudich et al. (1999; Paul Spudich, personal communication, 2001) for a predictive relation having the same functional form as equation (1). Please refer to Spudich et al. (1999) for a discussion of the collection and processing of the data. The coefficients from our PGV regression are listed in Table 1 and the relation is plotted in Figure 1.

Since we used the same data set as Spudich et al. (1999), we encountered the same data limitations. Like Spudich et al. (1999), we acknowledge that b_2 and b_3 cannot be determined in such a way as to give reliable results at large magnitudes. We fixed these values equal to b and c, respectively, from Joyner and Boore (1988). The Joyner and Boore (1988) data set had more PGV measurements for magnitudes greater than 7 than the SEA99 data set, thus providing a larger magnitude range. In a departure from the technique of Spudich et al. (1999), we chose to invert for the b_6 term. This decision was motivated by our experience in correcting the rock site bias for the PGA and PSV relations.

Formal analysis of the PGV regression suggests that the data are fit quite well. Using the maximum likelihood techniques discussed in the Appendix of Spudich et al. (1999), the calculated biases are -0.004 $\log_{10}$ units for rock and 0.005 $\log_{10}$ units for soil. These low biases help justify our decision to invert for b_6. Examining magnitude and distance dependencies of the PGV residuals (Figure 2), we note that there is a magnitude dependence for soil sites, as indicated by the significant slope of the maximum likelihood linear fit: -0.159 ± 0.066 (one std. dev.). It is very similar to the magnitude dependence of SEA99 residuals for 0.1 sec PSV, which Spudich et al. (1999) attribute to the paucity of data at high and low magnitudes. There does not appear to be a significant magnitude dependence for rock site residuals nor a significant distance dependence for rock or soil residuals. Considering the data distribution (Figure 2; Figure 4 of Joyner and Boore, 1988), we judge our PGV relation to be valid over the same magnitude and distance ranges as SEA99: **M** 5.0 to 7.7 and 0 to 100 km distance.

Comparison of our new PGV relation to that of Joyner and Boore (1988) shows that our relation predicts lower PGV for all magnitudes at distances out to 70 km (Figure 1). The difference at zero distance is a factor of 1.7 at rock sites and 1.6 at soil sites, and decreases with increasing distance. The two relations are similar at distances of 10 to 100 km, where the majority of the data used in both our study and Joyner and Boore (1988) lie.

As an alternative to PGV predictive relations, it is possible to estimate PGV using an empirical relation between PGV and 5%-damped 1-sec PSV from Newmark and Hall (1982):

$$\text{PGV} = \text{1-sec PSV} / 1.65 \qquad (9)$$

Due to the lack of recent PGV predictive relations, this Newmark and Hall method is gaining popularity. It is commonly used in HAZUS calculations and was included as the preferred PGV relation in the latest version of ShakeMap (v2.4). Comparison of our PGV relation to estimates made using equation (9) with our modified SEA99 1-sec PSV relation shows that at soil sites the relations are nearly identical (Figure 1). However, equation (9) systematically predicts lower ground motions at rock sites than our PGV relation. This difference increases with increasing magnitude. It was pointed out by Joyner and Boore (1988) that the relations between peak ground motions and response spectra depend on spectral shape which, in turn, depends on magnitude, distance, and site conditions. Because the data used by Newmark and Hall (1982) are mostly from soil sites, the difference at rock sites is not surprising.

Conclusions

We have corrected the bias in the rock site relations of SEA99. For PGA, we have demonstrated that our corrections reduce the overall bias. We recommend that our revised SEA99 predictive relations be used instead of the original SEA99 relations to estimate ground motions at rock sites in extensional tectonic regimes. We have also used data from the Spudich et al. (1999) study to empirically determine a PGV predictive relation appropriate for extensional regimes. Statistically, this relation is robust. We believe that it is an improvement over previously-determined PGV relations for applications in regions of active extension.

The corrections provided in this note to the PGA and PSV relations of SEA99, and the addition of a PGV predictive relation, are useful improvements to SEA99. Given the practical importance of PGV estimates, future ground motion prediction studies should develop equations for this parameter as well as for PGA and PSA/PSV.

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References

Abrahamson, N. A. and A. M. Becker (1997). Ground motion characterization at Yucca Mountain, Nevada, a report to the U.S. Geological Survey that fulfills Level 4 Milestone SPG28EM4, WBS Number 1.2.3.2.8.3.6.

Abrahamson, N. A. and K. M. Shedlock (1997). Overview, *Seism Res. Lett.* **68**, 9-23.

Abrahamson, N. A. and W. J. Silva (1997). Empirical response spectral attenuation relations for shallow crustal earthquakes, *Seism Res. Lett.* **68**, 94-127.

Arabasz, W. J., J. C. Pechmann, and E. D. Brown (1992). Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch front area, Utah, in *Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah*, P.L. Gori and W.W. Hays (Editors), *U.S. Geol. Surv. Profess. Paper 1500-A-J*, D1-D36.

Ashland, F. X. (2001). Site-response characterization for implementing ShakeMap in northern Utah, *Utah Geol. Surv. Report. of Investigation 248*, 10 pp., 2 pl.

Bjarnason, I. T., and J. C. Pechmann (1989). Contemporary tectonics of the Wasatch Front region, Utah, from earthquake focal mechanisms, *Bull. Seism. Soc. Am.* **79**, 731-755.

Boore, D. M., W. B. Joyner, and T. E. Fumal (1993). Estimation of response spectra and peak accelerations from western North American earthquakes: An interim report, *U.S. Geol. Surv. Open-File Rept. 93-509*, 72 pp.

Boore, D. M., W. B. Joyner, and T. E. Fumal (1994). Estimation of response spectra and peak accelerations from western North American earthquakes: An interim report, Part 2, *U.S. Geol. Surv. Open-File Rept. 94-127*, 40 pp.

Boore, D. M., W. B. Joyner, and T. E. Fumal (1997). Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes: A summary of recent work, *Seism Res. Lett.* **68**, 128-153.

Boore, D. M. and W. B. Joyner (1997). Site amplifications for generic rock sites, *Bull. Seim. Soc. Am.* **87**, 327-341.

Bjarnason, I.T., and J.C. Pechmann (1989). Contemporary tectonics of the Wasatch Front region, Utah, from earthquake focal mechanisms, *Bull. Seism. Soc. Am.* **79**, 731-755.

Campbell, K. W. (1997). Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra, *Seism Res. Lett.* **68**, 154-179.

Hanks, T. C. and H. Kanamori (1979). A moment-magnitude scale, *J. Geophys. Res.* **84**, 2348-2350.

Joyner, W. B. and D. M. Boore (1988). Measurement, characterization, and prediction of strong ground motion, in *Earthquake Engineering and Soil Dynamics II—Recent Advances in Ground-Motion Evaluation*, J. L. Von Thun (Editor), Geotechnical Specl. Pub. No. 20, Am. Soc. Civil Eng., New York, New York, 595 pp.

Joyner, W. B. and D. M. Boore (1993). Methods for regression analysis of strong-motion data, *Bull. Seism. Soc. Am.* **83**, 469-487.

Joyner, W. B. and D. M. Boore (1994). Errata: Methods for regression analysis of strong-motion data, *Bull. Seism. Soc. Am.* **84**, 955-956.

Newmark, N. M., and W. J. Hall, (1982). *Earthquake Spectra and Design*, Earthquake Engineering Research Institute, Berkeley, California, 103 pp.

National Institute of Building Sciences (1999a). *HAZUS User's Manual*, U. S. Federal Emergency Management Agency, Washington, D.C.

National Institute of Building Sciences (1999b). *HAZUS Technical Manual*, U. S. Federal Emergency Management Agency, Washington, D.C.

Sadigh, K., C.-Y. Chang, J. A. Egan, F. Makdisi, and R. R. Youngs (1997). Attenuation relationships for shallow crustal earthquakes based on California strong motion data, *Seism Res. Lett.* **68**, 180-189.

Smith, R. B. and W. J. Arabasz (1991). Seismicity of the Intermountain seismic belt, in *Neotectonics of North America*, D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, (Editors), *Geol. Soc. Am. Decade Map Vol. 1*, 185-228.

Spudich, P., J. B. Fletcher, M. Hellweg, J. Boatwright, C. Sullivan, W. B. Joyner, T. C. Hanks, D. M. Boore, A. McGarr, L. M. Baker, and A. G. Lindh (1996). Earthquake ground motions in extensional tectonic regimes, *U.S. Geol. Surv. Open-File Rept. 96-292*, 351 pp.

Spudich, P., J. B. Fletcher, M. Hellweg, J. Boatwright, C. Sullivan, W. B. Joyner, T. C. Hanks, D. M. Boore, A. McGarr, L. M. Baker, and A. G. Lindh (1997). SEA96: A new predictive relation for earthquake ground motions in extensional tectonic regimes, *Seism Res. Lett.* **68**, 190-198.

Spudich, P., W. B. Joyner, A. G. Lindh, D. M. Boore, B. M. Margaris, and J. B. Fletcher (1999). SEA99: A revised ground motion prediction relation for use in extensional tectonic regimes, *Bull. Seism. Soc. Am.* **89**, 1156-1170.

Wald, D. J., V. Quitoriano, T. H. Heaton, H. Kanamori, C. W. Scrivner, and C. B. Worden (1999a). TriNet "ShakeMaps": Rapid generation of peak ground motion and intensity maps for earthquakes in southern California, *Earthquake Spectra* **15**, 537-555.

Wald, D. J., V. Quitoriano, T. H. Heaton, and H. Kanamori (1999b). Relationships between peak ground acceleration, peak ground velocity, and Modified Mercalli intensity in California, *Earthquake Spectra* **15**, 557-564.

Table 1
Coefficients for PGV Relation and Revised SEA99 PGA and 5% Damped PSV Relations

Period (sec)	B_v*	b_1	b_2†	B_3†	b_5†	b_6	h (km)†	$\sigma_{\log Z}$ ‡	σ_3
PGV	--------	2.252	0.490	0	-1.196	0.195	7.06	0.246	0.106
PGA	-0.371	0.237	0.229	0	-1.052	0.174	7.27	0.203	0.094
0.100	-0.212	2.109	0.327	-0.098	-1.250	0.099	9.99	0.273	0.110
0.110	-0.211	2.120	0.318	-0.100	-1.207	0.099	9.84	0.265	0.111
0.120	-0.215	2.129	0.313	-0.101	-1.173	0.101	9.69	0.257	0.113
0.130	-0.221	2.138	0.309	-0.101	-1.145	0.103	9.54	0.252	0.114
0.140	-0.228	2.145	0.307	-0.100	-1.122	0.107	9.39	0.247	0.115
0.150	-0.238	2.152	0.305	-0.099	-1.103	0.111	9.25	0.242	0.116
0.160	-0.248	2.158	0.305	-0.098	-1.088	0.116	9.12	0.239	0.117
0.170	-0.258	2.163	0.305	-0.096	-1.075	0.121	8.99	0.237	0.118
0.180	-0.270	2.167	0.306	-0.094	-1.064	0.126	8.86	0.235	0.119
0.190	-0.281	2.172	0.308	-0.092	-1.055	0.131	8.74	0.234	0.119
0.200	-0.292	2.175	0.309	-0.090	-1.047	0.137	8.63	0.233	0.120
0.220	-0.315	2.182	0.313	-0.086	-1.036	0.147	8.41	0.231	0.121
0.240	-0.338	2.186	0.318	-0.082	-1.029	0.158	8.22	0.231	0.122
0.260	-0.360	2.190	0.323	-0.078	-1.024	0.168	8.04	0.231	0.123
0.280	-0.381	2.194	0.329	-0.073	-1.021	0.178	7.87	0.231	0.124
0.300	-0.401	2.196	0.334	-0.070	-1.020	0.188	7.72	0.232	0.125
0.320	-0.420	2.198	0.340	-0.066	-1.019	0.196	7.58	0.232	0.126
0.340	-0.438	2.199	0.345	-0.062	-1.020	0.205	7.45	0.233	0.126
0.360	-0.456	2.200	0.350	-0.059	-1.021	0.213	7.33	0.234	0.127
0.380	-0.472	2.200	0.356	-0.055	-1.023	0.221	7.22	0.236	0.128
0.400	-0.487	2.201	0.361	-0.052	-1.025	0.228	7.11	0.237	0.128
0.420	-0.502	2.201	0.365	-0.049	-1.027	0.235	7.02	0.238	0.129
0.440	-0.516	2.201	0.370	-0.047	-1.030	0.241	6.93	0.239	0.129
0.460	-0.529	2.201	0.375	-0.044	-1.032	0.247	6.85	0.241	0.129
0.480	-0.541	2.201	0.379	-0.042	-1.035	0.253	6.77	0.242	0.130
0.500	-0.553	2.199	0.384	-0.039	-1.038	0.259	6.70	0.243	0.130
0.550	-0.579	2.197	0.394	-0.034	-1.044	0.271	6.55	0.246	0.131
0.600	-0.602	2.195	0.403	-0.030	-1.051	0.281	6.42	0.249	0.132
0.650	-0.622	2.191	0.411	-0.026	-1.057	0.291	6.32	0.252	0.132
0.700	-0.639	2.187	0.418	-0.023	-1.062	0.299	6.23	0.254	0.133
0.750	-0.653	2.184	0.425	-0.020	-1.067	0.305	6.17	0.257	0.133

Period (sec)	B_v*	b_1	b_2†	B_3†	b_5†	b_6	h (km)†	σ_{logZ} ‡	σ_3
0.800	-0.666	2.179	0.431	-0.018	-1.071	0.311	6.11	0.260	0.134
0.850	-0.676	2.174	0.437	-0.016	-1.075	0.316	6.07	0.262	0.134
0.900	-0.685	2.170	0.442	-0.015	-1.078	0.320	6.04	0.264	0.134
0.950	-0.692	2.164	0.446	-0.014	-1.081	0.324	6.02	0.267	0.135
1.000	-0.698	2.160	0.450	-0.014	-1.083	0.326	6.01	0.269	0.135
1.100	-0.706	2.150	0.457	-0.013	-1.085	0.330	6.01	0.273	0.135
1.200	-0.710	2.140	0.462	-0.014	-1.086	0.332	6.03	0.278	0.136
1.300	-0.711	2.129	0.466	-0.015	-1.085	0.333	6.07	0.282	0.136
1.400	-0.709	2.119	0.469	-0.017	-1.083	0.331	6.13	0.286	0.136
1.500	-0.704	2.109	0.471	-0.019	-1.079	0.329	6.21	0.291	0.137
1.600	-0.697	2.099	0.472	-0.022	-1.075	0.326	6.29	0.295	0.137
1.700	-0.689	2.088	0.473	-0.025	-1.070	0.322	6.39	0.299	0.137
1.800	-0.679	2.079	0.472	-0.029	-1.063	0.317	6.49	0.303	0.137
1.900	-0.667	2.069	0.472	-0.032	-1.056	0.312	6.60	0.307	0.137
2.000	-0.655	2.059	0.471	-0.037	-1.049	0.306	6.71	0.312	0.137

*From Table 8 of Boore et al. (1997)

† From Table 2 of Spudich et al. (1999)

‡ Calculated from Table 2 of Spudich et al. (1999) using $\sigma_{\mathrm{logZ}} = (\sigma_1^2 - \sigma_2^2)^{1/2}$

Figure Captions

Figure 1. Predictions of peak horizontal ground velocity versus Joyner-Boore distance at (a) rock and (b) soil sites from earthquakes of moment magnitude 5.0, 6.0, and 7.0. The solid lines are from this study and the dashed lines are from Boore et al. (1988). The dotted lines were obtained by converting 1-sec 5%-damped pseudovelocity (PSV) from our modified version of SEA99 to peak ground velocity using an adjustment factor of 1/1.65 (Newmark and Hall, 1982).

Figure 2. Horizontal peak ground velocity (PGV) residuals, defined as Log_{10} (Observed PGV) - Log_{10} (Predicted PGV), versus moment magnitude (a) and Joyner-Boore distance (b) for our extensional regime PGV relation. Data points for distances of less than 1 km are plotted at 1 km distance. The dashed and dotted lines are maximum likelihood fits to the data points for rock sites (triangles) and soil sites (circles), respectively. The slopes of the lines, with one-standard-deviation error bars, are as follows: (a) rock (dashed) = -0.012 ± 0.072, soil (dotted) = -0.159 ± 0.066, (b) rock (dashed) = 0.066 ± 0.136, soil (dotted) = 0.004 ± 0.079.

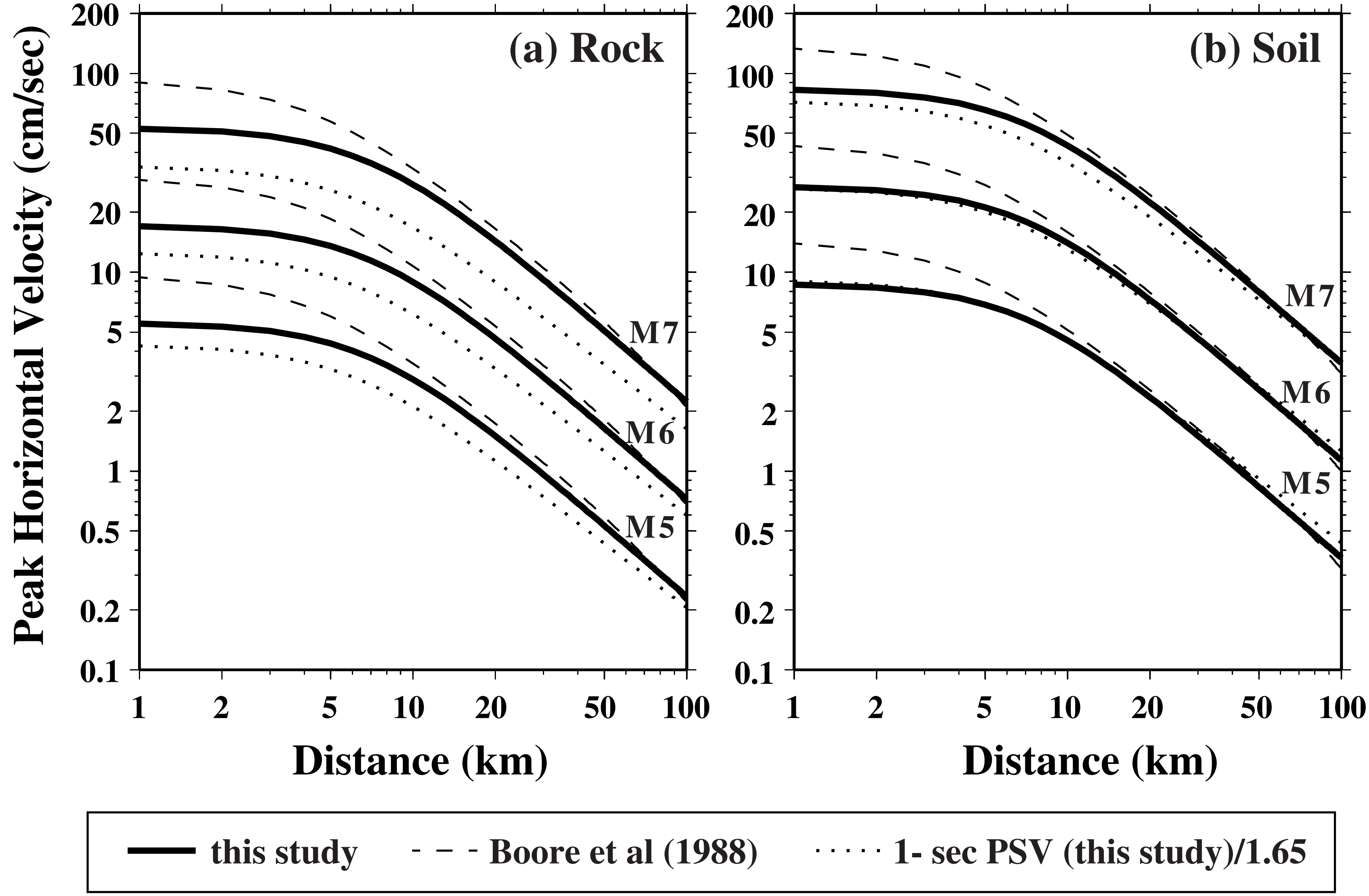
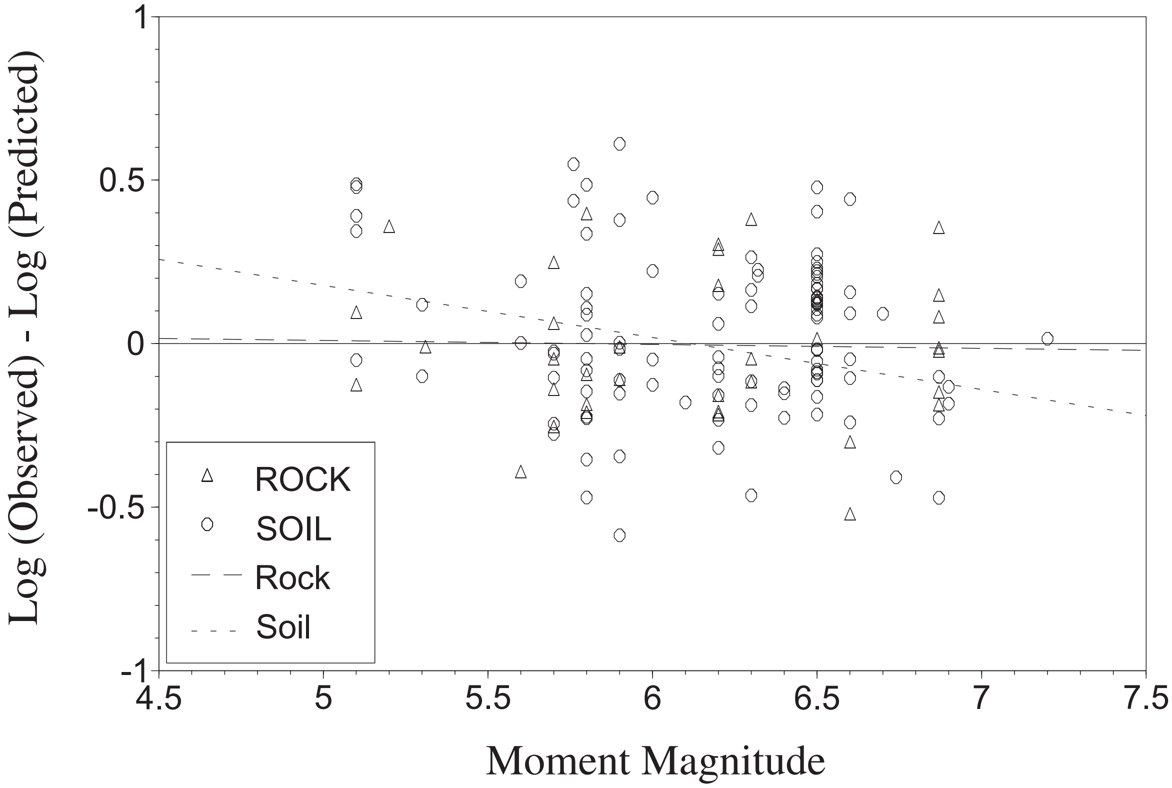

Peak Horizontal Velocity (cm/sec)
(a) Rock
(b) Soil
M7
M6
M5
200
100
50
20
10
5
2
1
0.5
0.2
0.1
1
2
5
10
20
50
100
Distance (km)
this study
Boore et al (1988)
1- sec PSV (this study)/1.65

Figure 1

(A) PGV RESIDUALS VS. MAGNITUDE



(B) PGV RESIDUALS VS. DISTANCE

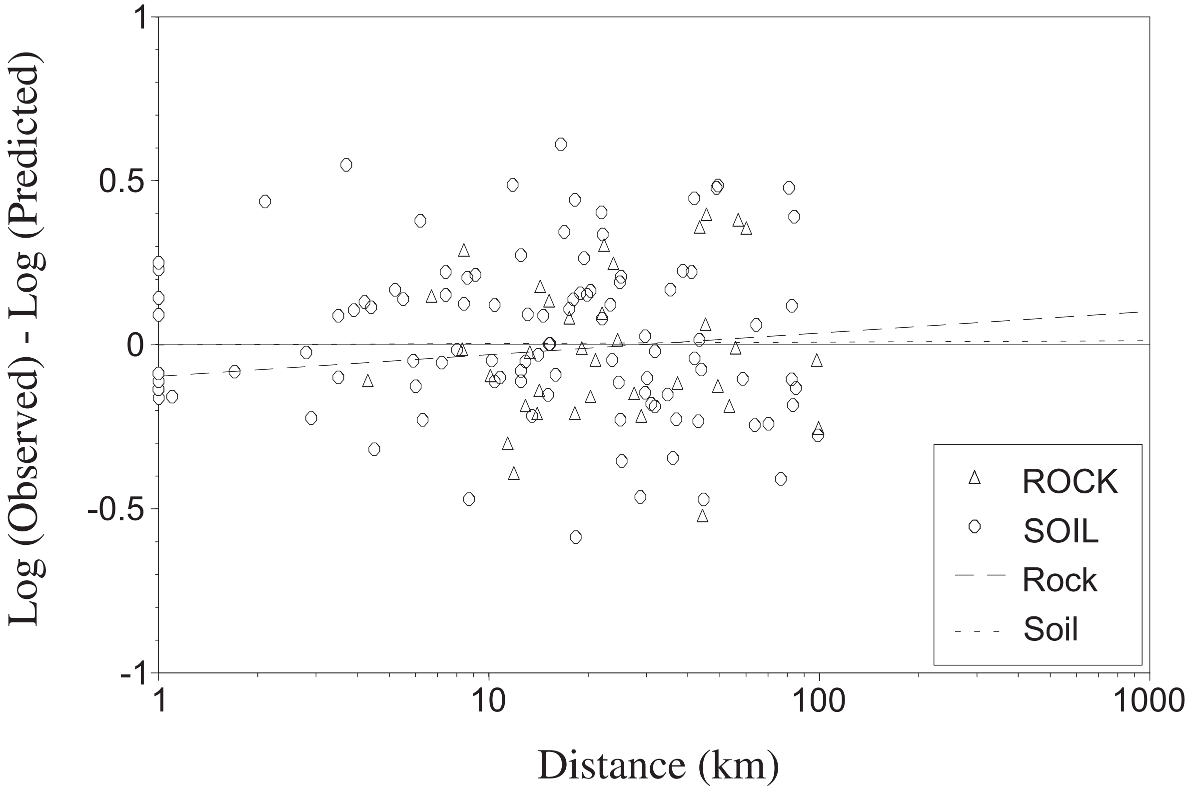


Figure 2

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